10.0 RI CONCEPTUAL SITE MODEL SUMMARY

The CSM for the Portland Harbor study area is sumarized in this section. A CSM is a representation of an environmental system and the biological, physical, and chemical processes that affect the transport of contaminants from sources through environmental media to human and ecological receptors in the system. This section presents a CSM for the Portland Harbor Site that draws on and synthesizes supporting information presented previously in this RI. Specifically, this includes the physical setting information detailed in Section 3, the source information presented in Section 4, the contaminant distributions across all media described in Section 5, the contaminant loading, fate and transport evaluations presented in Section 6, and finally, the human health and ecological risk assessments summarized in Sections 8 and 9, respectively.[1]

Section 10.1 presents a study area-wide overview of the physical setting; contaminant distribution in sediments; contamination sources identified to date; external loading and internal fate and transport mechanisms; and human health and ecological receptors, and exposure pathways and scenarios.

Section 10.2 is a CSM presentation for the specific indicator contaminants described in Section 5, consistent with USEPA (2005d) guidance. It includes a series of contaminant-specific maps of the study area's abiotic and biotic data sets that illustrate relationships between the observed contaminant distributions and known and likely historical and current sources and pathways. These displays are intended to provide a picture of the distribution, transport, and fate of contaminants in the study area across a range of physical, chemical, and biological processes, as well as potential sources.

The objective of this CSM is to illustrate our understanding of the sources and fate and transport mechanisms that determine the observed distribution of individual contaminants in affected abiotic and biotic media across the study area, based on the information and data collected, compiled, and evaluated in this RI.

10.1   SITE CONCEPTUALIZATION

A pictorial representation illustrating the major elements of the CSM (sources, pathways, fate and transport mechanisms, and human and ecological receptors) for the Portland Harbor study area is shown in Figure 10.1-1, while Figure 10.1-2 presents a graphical conceptualization of the sources, release mechanisms, transport media, and exposure media of the CSM. The detailed human health and ecological CSMs for the Portland Harbor Site are summarized in Appendix F, Figure 3-1 and Appendix G, Attachment 2, Figure 1 (also RI Section 9, Figure 9.6-1), respectively, and focus on exposure routes and receptor groups.

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[1] Section 7 of this RI details the approach used to generate background concentrations for the site contaminants for use in the FS. This information is not summarized here in Section 10.

10.1.1   Physical Setting and Sediment Dynamics

The Portland Harbor study area (RM 1.9 to 11.8 of the Willamette River) is located at the downstream end of the lower Willamette River, which extends from the Willamette Falls at RM 26 to its convergence with Columbia River at RM 0. In its natural, undisturbed state, the study area reach was relatively shallow and meandering, surrounded by uplands, forested wetlands, and floodplains. Over the last century, much of the original riverbed has been dredged and the adjacent riverbanks have been filled, stabilized, and/or engineered for commercial, industrial, and marine operations with riprap, bulkheads, and overwater piers and docks. The extensive physical alteration and the associated anthropogenic activities as well as upstream river-stage control through the construction and management of dams, have resulted in a river reach that little resembles its pre-industrialized character in terms of hydrodynamics, sediment processes, and ecological habitat.

The effect of the multipurpose dams has been to dampen the flows during seasonal and storm events. The Columbia River also plays a role in the flow dynamics of the Willamette River. In spring, high flows in the Columbia River can increase the hydraulic head at the confluence causing the Willamette River to be detained and reduce flows until water levels drop in both river systems. Tidal action also compounds the hydrology and interplay of the two rivers, and affects the Willamette River upstream as far as Portland Harbor and beyond. These tidal fluctuations can result in short-term flow reversals (i.e., upstream flow) in Portland Harbor during times of extremely low river stage combined with a large variation in tide levels, which can occur in late summer to early fall.

Within the study area, there are distinct reaches that share similar hydrodynamic and sediment bed characteristics (see Section 3.1.5.2). Because of the affinity of both organic and inorganic contaminants to be associated with particulates, the transport and fate of sediments in the study area strongly affects the distribution of most contaminants. The primary factors controlling river flow dynamics, sediment deposition and erosion, and riverbed character appear to be the river cross-sectional area and navigation channel width. The upstream boundary of the study area to Willamette Falls is markedly narrower, more confined by bedrock outcrops, and faster flowing than the Portland Harbor reach. The river widens as it enters the study area and becomes increasing depositional, especially in the western portion of the river, until RM 7. From about RM 7 to 5, the river and navigation channel narrow, and this reach is dominated by higher energy environments with little deposition. From RM 5 to about RM 2, the river widens again and becomes depositional, especially in the eastern portion of the river. Immediately downstream of the study area, the river narrows as it turns and converges with the Columbia River. Multnomah Channel exits at RM 3, considerably reducing discharge to the Columbia River.

Sediment accumulation data from the sediment traps provides information on the mobile sediment loads at the site. Table 5.3-1 presents data showing that sediment accumulation rates in sediment traps placed throughout the site in 2007 and 2009 range

from less than 1 cm to approximately 69 cm per quarter. Twelve of the 16 traps deployed in the fall and eight of the 16 traps deployed in the winter had accumulations exceeding 5 cm per quarter.

While much of this suspended load passes through the study area (see Section 6.2.1.3), long-term net sedimentation rates in the study area were estimated based on time-series bathymetric surveys and other lines of evidence (e.g., sediment accumulation in borrow pits). The measured riverbed elevation changes over the 7-year period from 2002 to 2009 illustrates a pattern of general shoaling in the relatively wide reaches from RM 7 to 10 and RM 2 to 5, and no change or scour in the higher energy, narrow reaches upstream of RM 10 and between RM 5 and 7 (Map 3.1-6) The maximum net sedimentation accumulation rates (exceeding 30 cm/yr in some places) occur in the navigation channel between RM 8 and 10 and in the upstream borrow pits at RM 10.5 and 10.9.

The western half of the navigation channel from RM 8 to 10 has historically required regular maintenance dredging. Bathymetric change data from 2002 to 2009 in the downstream channel shoaling area, which begins at RM 2.8 and extends downstream towards RM 1.5 showed a net maximum sediment accumulation rate of about 18 cm/yr at RM 2 over this 7-year time frame (Map 3.1-6). The decrease in net sedimentation rates between upstream and downstream channel shoaling areas is consistent with a single major source of sediments that enter the study area from upstream and settle out or are trapped in depressions and shoaling areas as they move downstream.

Bathymetric change data, SPI observations (SEA 2002b), and the radioisotope sampling (Anchor 2005b) data indicate that sediments do not generally accumulate in nearshore areas at the levels they do in the shoaling areas in the main channel. Nonetheless, many nearshore areas exhibit fine-grained sediment accumulation based on both bathymetric change data and SPI interpretation. The bathymetric change data (Map 3.1-6) shows that some nearshore areas (RM 2–3E, RM 4–5, RM 7–8, RM 8–9W) show net sedimentation rates of at least 4 cm/yr (total sediment accumulations exceeding 30 cm from 2002 to 2009). In other areas, such as RM 9-11E, areas within Swan Island Lagoon and Willamette Cove, RM 6-7W, and RM 5-7E, little net elevation change and/or small-scale scour was observed.

10.1.2   Contaminant Distribution

This section provides a brief overview of the overall distribution of contaminants in study area sediments. Based on examination of the contaminant distribution trends, some general patterns emerge among subsets of different contaminants that reflect study area fate and transport processes, as well as the relative importance of regional versus study area sources. These patterns are discussed below.

Sediment contaminant concentrations are greatest in nearshore areas.
Concentrations of contaminants are generally higher in localized nearshore and off-

channel areas as compared to sediments in the navigation channel, Multnomah Channel, and downstream areas.

Organic contaminant concentrations are greater in subsurface sediments.
Concentrations of organic contaminants tend to be higher in subsurface sediments than in surface sediments. Concentrations of total PCBs, DDx, total PAHs, hexachlorobenzene, total chlordanes, aldrin and dieldrin, gamma-HCH, lead, and TBT are higher in subsurface than in surface sediments, indicating that historical inputs were likely greater than current inputs. In contrast, arsenic, copper, chromium, mercury, and zinc do not have large concentration ranges and generally show similar levels in surface and subsurface sediments.

Regional inputs exhibit uniform concentrations across the area. Contaminants that may be derived predominantly from regional or upstream inputs show widespread surface sediment distributions without distinct, isolated areas of higher concentrations. Examples of this are arsenic, chromium, and mercury, which occur at relatively low concentrations throughout the study area, and no strong concentration gradients are apparent.

Areas of high concentrations are present throughout the study area and generally are associated with known upland sources. A number of contaminants exhibit relatively high sediment concentrations in distinct areas offshore of known or likely sources. These areas are separated by large areas with relatively lower concentrations lacking obvious concentration gradients. Contaminants that exhibit this trend include total PCBs, TCDD, BEHP, butylbenzyl phthalate, PCP, hexachlorobenzene, total chlordanes, gamma-HCH, copper, zinc, and TBT.

Some contaminants have areas of high concentrations that are more common in the lower (downstream) half of the study area. DDx and total PAHs exhibit elevated concentrations at locations adjacent to known upland sources. Concentrations of these contaminants are elevated relative to upstream concentrations.

Concentrations of certain metals are correlated to sediment grain size: A comparison of metals concentrations to the distributions of percent fines in the study area shows that where sediments are composed of less than 40 percent fines, chromium and copper concentrations are relatively low (above RM 10, between RM 5 and 7, and in the Multnomah Channel. A similar, but less pronounced, correspondence exists between sandy sediments and zinc concentrations.

Multiple contaminants co-occur: Several locations within the study area have relatively high surface sediment concentrations of more than one contaminant. Some of these areas and the co-occurring contaminants are as follows:

- **RM 11E:** total PCBs, total PCDD/Fs, DDx, chromium, copper

- **RM 9.7W:** total PCBs, total PCDD/Fs, BEHP, zinc

- **RM 8.7–9.3W:** total PCBs, total PCDD/Fs, total PAHs, total chlordanes, copper, mercury, nickel, zinc

- **RM 8.3W:** total PCBs, total PAHs, BEHP, total chlordanes, dieldrin, lead, copper

- **Swan Island Lagoon:** total PCBs, total PCDD/Fs, total PAHs, BEHP, total chlordanes, chromium, copper, zinc, TBT

- **RM 6.8–7.5W:** total PCDD/Fs, DDx

- **RM 6.7–6.8E:** total PCBs, total PCDD/Fs, copper

- **RM 5.6–5.7E:** total PCDD/Fs, total PAHs, total chlordanes, gamma-HCH, chromium, copper, lead, mercury, zinc,

- **RM 4.3–4.5E:** total PCBs, total PCDD/Fs, total PAHs, total chlordanes, zinc

- **International Slip:** total PCBs, total PCDD/Fs, total PAHs, BEHP, total chlordanes, chromium, copper, lead, zinc, TBT.

This degree of contaminant co-occurrence in specific study area locations reflects the history of upland site development, including wastewater and stormwater conveyance systems and industrial and commercial activities, as described in Section 4 and summarized in Section 10.1.3 below.

10.1.3 Site Sources

The following is a summary of information and the sources of that information presented in Section 4 on the nature of historical and current sources and associated pathways to the study area known thus far.[2]

10.1.3.1 Historical

Historical sources dating back to the early 1900s contributed to the majority of the observed contaminant distributions in sediments within the study area. This is reflected in the extent and degree of subsurface sediment contamination as discussed in the previous section. Nearly all the identified chemical pathways have a historical component.

In the early 1900s, rivers in the United States were generally used as open sewers, which was also true for the Willamette (Carter 2006). Untreated sewage, contaminated

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[2] The source information presented in this Portland Harbor RI report is a compilation of public information available from site owners and operators and from DEQ, and is based upon information provided through September 2010, and DEQ's September 2010 Source Control Milestone Report. Detail regarding the origins and scope of the source control information is presented in Section 4. Source information will be updated in future DEQ Source Control documents.

stormwater runoff from various land uses, as well as process water from a variety of industries, including slaughterhouses, lumber mills, paper mills, and food processors, was discharged directly into the river, as were pollutants from less conspicuous (non-point) sources, including agricultural fields, oil spills, rubber and oils, and garbage dumps. With the exception of manufactured gas operations and bulk fuel storage, which began in the late 1800s, most chemical manufacturing and use began in the 1930s.

Commercial and industrial development in Portland Harbor accelerated prior to World War I and again during World War II. These industrial operations and their associated COIs are discussed in more detail in Section 4 and summarized here:

- **Ship Building, Dismantling, and Repair.** VOCs, SVOCs, PAHs, PCBs, TPH, copper, zinc, chromium, lead, mercury, phthalates, and butyltins are common sediment contaminants associated with shipyards. Approximate areas of former shipyards include RM 4E, 5.6E, 7E, 7.4E, Swan Island, RM 9W, 10W, and 11E. Ship building continues at a much smaller scale in Portland Harbor today, with most work focused on ship maintenance and repair.

- **Wood Products and Wood Treating.** COIs typically associated with sawmills include metals, TPH, and PAHs. In addition to these COIs, plywood manufacturing could include VOCs and SVOCs, as well as possibly pesticides and fungicides (Eaton et al. 1949; USFS 1964; Moore and Loper 1980; Stellman 1998). Lumber mills and wood treatment facilities operated at various locations within the study area historically. McCormick and Baxter, a large wood-treating facility, was located at RM 6.9–7.2E. COIs associated with wood treatment include creosote/diesel oil mixtures, PCP, and a variety of water- and ammonia-based solutions containing arsenic, chromium, copper, and zinc (USEPA 2006d). PCP wood treatment products routinely contain dioxin/furans as contaminants, and these are an additional COI of wood treatment facilities (USEPA 2004a). Many other lumber mills and plywood manufacturers were found throughout the study area, including Linnton Plywood, St. Johns Lumber (which operated on the present-day Crawford Street and BES Water Pollution Control Laboratory sites), Kingston Lumber, and former mills in Willamette Cove.

- **Chemical Manufacturing and Distribution.** Chemical plants within the study area (RM 6.8–7.5W) that manufactured pesticides and herbicides were in place as early as 1941. Rhone Poulenc and Arkema were the two primary pesticide and herbicide manufacturers in this area. Several distributors of chemicals have existed at the Site, including Univar and Mt. Hood Chemical. COIs typically associated with these operations include pesticides, herbicides, VOCs, dioxins/furans, and metals (especially arsenic).

- **Metal Recycling, Production, and Fabrication.** Metal salvage and recycling facilities operated at RM 4E, 5.8W, 7.3W (Schnitzer-Doane Lake), 8.5W (Calbag/Acme), 8.9W (Gunderson – Former Schnitzer Steel auto dismantling),

and 10W (Calbag) in the study area, and several scattered locations upriver. COIs commonly found in waste streams from metal recycling facilities include VOCs, TPH, PCBs, phthalates, cyanide, and a variety of metals. Metal production and fabrication currently takes place in the Burgard Industrial Park and several sites in the RM 8 to 10.3W reach. COIs associated with metal production and fabrication include metals, PAHs, and TPH. Hydraulic oil with PCBs was often used for high-temperature applications such as die-casting machines. Metal plating also has occurred at a few locations in the study area, including Columbia American Plating at RM 9.5W. COIs associated with metal plating activities include VOCs, PAHs, TPH, cyanide, and several metals.

- **Manufactured Gas Production.** Manufactured gas production operations took place between 1913 and 1956 at Portland Gas & Coke (RM 6.2W). The Pintsch Compressing Company Gas Works operated between 1890 and the mid-1930s at RM 7.3W and manufactured compressed gas from crude oil for railroad train lighting. Prior to 1913, gas production also occurred just upstream of the study area at the Portland MGP site at RM 12.2E. COIs associated with manufactured gas operations include VOCs, SVOCs, TPH, PAHs, metals, and cyanide.

- **Electrical Production and Distribution.** Electrical transformers and capacitors are associated with all of the major industries in the harbor. Some of these transformers and capacitors may contain PCBs. Seven current and one historical substation are found in the study area. Transformer repair, servicing, and salvaging operations were found on the east bank from RM 11.3 to 11.5 (Tucker Building, Westinghouse, and PacifiCorp Albina Properties), at RM 3.7W (ACF Industries), RM 9.5E (Portable Equipment Salvage), RM 9.5W (GE Decommissioning), and the GE facility at NW 28th Ave (TSCA site). COIs linked with these types of operations include PAHs, TPH, and PCBs.

- **Bulk Fuel Distribution and Storage and Asphalt Manufacturing.** Bulk fuel facilities have a long history in Portland Harbor. By 1936, most of the facilities currently in place had been established between RM 4 and 8 on the west side of the river. COIs typically associated with bulk fuel storage operations include VOCs, SVOCs, PAHs, TPH, and metals.

- **Steel Mills, Smelters, and Foundries.** Several foundries were located within the study area, at RM 11.4W (Gender Machine Works), RM 9.7W (Schmitt Forge), and RM 2.7E (Consolidated Metco). Smelters were located at RM 7.2W (Gould), RM 9W (National Lead/Magnus Smelter), and RM 11.6W (RiverTec Property). Steel mills are or were located at RM 2.4E (Evraz, aka Oregon Steel Mill) and at RM 8.3W (former Oregon Steel Mill operation at Front Ave LP). COIs associated with these types of operations include metals, TPH, PCBs, and PAHs. PCBs were a component of hydraulic fluid for high temperature applications (machining and die casting) where fire resistance was important, and were also a component of heat transfer fluid used in applications like heat exchangers and recirculating cooling systems.

- **Commodities Maritime Shipping and Associated Marine Operations.** In addition to the Port of Portland's large presence in Portland Harbor with three deep-water terminals committed to import/export, currently there are or have been several other commodity shipping facilities in the harbor (Map 3.2-20). These include the grain handling operations at CLD Pacific Grain (RM 11.4E) and Centennial Mills (RM 11.3W), edible oils at the former Premier Edible Oils facility (RM 3.6E), scrap metal export at International Terminals (RM 3.7E), cement import and distribution at Glacier NW (RM 11.3E), anhydrous ammonia and solid and granular urea at JR Simplot in the South Rivergate Industrial Park (RM 3E), and alumina, electrode binder pitch, and grain at the former Goldendale Aluminum property (RM 10E). Supporting maritime activities include overwater tug and barge moorage, maintenance and repair facilities, overwater bunkering and lightering, tug-assisted and independent maneuvering of vessels in and around marine facilities, and stevedoring (loading and discharging) product at vessels. Incidental spills into the river from commodities maritime shipping include organic materials, VOCs, PAHs, and TPH.

- **Rail Yards.** Rail yard and freight car repair facilities operated at several locations within the study area. Active facilities are located at approximately RM 9.8 to 11.1E (UPRR Albina Yard), RM 8.6 to 9.5W (PTRR Guilds Lake Yard), and RM 4.8E (UPRR – St. Johns Tank Farm). Historical rail yard operations were located at and around RM 11.6W (BNSF Hoyt Street Railyard, and UPRR Union Station operations). Historical rail car maintenance operations were located at RM 3.6 (ACF Industries). Dependent on the activities conducted, COIs could include VOCs, SVOCs, TPH, PCBs, and metals.

Contaminant migration to in-water media occurs through several migration pathways, including stormwater, industrial wastewater, overland flow, groundwater, bank erosion, and overwater releases. Contaminated surface soils in upland areas and along riverbanks can be carried directly to the river as riverbank erosion and in stormwater runoff, particularly during high flows and floods. In some locations, contaminated dredged material may have been placed in low-lying areas subject to erosion. While the quality of this fill material is generally undocumented, because of the history of sediment contamination from industrial and maritime sources, contaminated sediment could have been included in fill material.

Migration of contaminants from upland areas to the river via groundwater is a historical source of contamination to the river at a limited number of upland sites within the study area. At a subset of these sites, the historical groundwater pathway has contributed significant loading of upland contaminants to sediment and TZW. While some complete historical groundwater transport pathways have been mitigated or eliminated through source control actions, others remain complete, as identified in Section 10.1.3.2 below.

Overwater releases were likely common occurrences at industries that relied on maritime shipping and located on the banks of the Willamette River, and are likely important historical contributors to in-water contamination. However, prior to the relatively recent enactment of reporting requirements, overwater spills were generally undocumented.

Upstream sources also contributed to the historical contamination of the lower Willamette River. These sources included sewerage, stormwater runoff, and direct discharge of industrial wastes from upstream cities, towns, and industrial areas; agricultural runoff; and aerial deposition on the water surface and drainage areas within the Willamette Valley.

10.1.3.2   Current

Operations that continue to exist today include bulk fuel storage, barge building, ship repair, automobile scrapping, recycling, steel manufacturing, cement manufacturing, transformer reconditioning, operation and repair of electrical transformers (including electrical substations), and many smaller industrial operations. Locations of both current and historical major industrial operations in Portland Harbor are presented on Map 3.2-10 and Maps 3.2-13 through 3.2-21.

Stormwater and wastewater discharges are regulated and permitted for many of the sites adjacent to the study area. However, sampling for RI-related chemicals in stormwater and catch basins only began in recent years and, for the most part, has only been done for those facilities that have voluntarily conducted a stormwater source control evaluation. With the construction of stormwater treatment systems and wastewater treatment systems over the years, overland transport has been largely abated at most sites. A current likely complete overland transport pathway has been identified at very few sites.

Current known complete or likely complete groundwater pathways have been identified at 11 sites, 51 sites have insufficient data to make a determination, and 58 sites have been identified as not having a complete pathway. The groundwater pathway assessment conducted during the RI consisted of detailed groundwater discharge and TZW sampling at nine high priority sites. Based on these efforts, a current complete groundwater pathway with influence on TZW and sediment chemistry was confirmed at four sites, groundwater migration was found to have no significant influence at four other sites, and groundwater effects could not be determined at one site (see Appendix C2).

Riverbank erosion from contaminated and unstabilized bank areas may represent an ongoing release mechanism in the study area. Currently, about 75 percent of the riverbanks within the study area are stabilized and armored with various materials, including seawalls, riprap, and engineered and non-engineered soil. Known or likely complete riverbank pathways have been identified at a few sites with unstabilized banks.

The activities most commonly associated with current overwater spills in the study area are product handling, overwater activities such as refueling, and spills from vessels. Overwater releases are likely important contributors to in-water contamination at sites that have long histories of overwater operations and product transfers. Spill records collected over the past approximately 30 years do not generally record large releases, but there have been some exceptions.

DEQ's JSCS program focuses on the abatement of current and threatened future releases of contaminants to the study area. The current status of that program is summarized in Section 4.4.7.

As with historical sources, current upriver sources also play a role in the contaminant distribution in the lower Willamette River. Current upstream loading is discussed in the following section.

10.1.4   Loading, Fate and Transport

This section summarizes the information detailed in Section 6 of the RI on contaminant mass inputs and internal mass transfer mechanisms within the study area on a site-wide basis. A comparison of the relative magnitude of these terms is presented for each indicator contaminant in Section 10.2. External loads include upstream loading via surface water and sediment bedload, stormwater, permitted industrial discharges, upland groundwater transport, atmospheric deposition, upland soil and riverbank erosion, groundwater advection through subsurface sediments, and overwater releases.

Upstream loading represents the largest current contaminant loading term for the studyarea. While upstream surface water and suspended sediment concentrations are typically lower than those measured in the study area, the very large flow volume of the river compared to the flow volumes for the other loading terms results in a relatively large mass load of contaminants compared to other current sources. With the exception of total PAHs and TBT, upstream loading is greater than other loading terms by 1 to 3 orders of magnitude for all of the indicator contaminants. Estimated flow volumes used for the various loading terms are presented on Figure 10.1-3.

Stormwater runoff is the second largest quantified annual external loading term to the study area for all indicator chemicals except total PAHs and arsenic (dioxins/furans and TBT were not sampled in stormwater). Loading from CSO discharges is also a factor. Contaminants present in stormwater runoff are transported mostly via conveyance systems and discharged through numerous outfalls along the river shoreline within the study area. Overland flow of stormwater to the river also occurs in some relatively limited areas.

The other external loading mechanisms (permitted discharges, groundwater transport, atmospheric deposition, direct upland soil and riverbank erosion, groundwater advection through subsurface sediments, and overwater releases) are generally lower in

magnitude than the upstream and stormwater loading. Where notable, the other mechanisms are discussed on a contaminant-specific basis in Section 10.2

Internal transfer mechanisms involve the transport of contaminant mass from one media to another within the study area, but do not add new contaminant mass to the study area. Internal fate and transport mechanisms include sediment resuspension, transport, and deposition, solid/aqueous-phase partitioning, abiotic/biotic transformation and degradation, biological uptake and depuration, and partitioning from surface sediment to surface water. Due to the hydrophobic nature of most of the organic contaminants found in the study area, they tend to preferentially partition to the dissolved and particulate organic matter.

Lateral and vertical movement of chemicals in surface water occurs primarily as a result of turbulent (eddy) dispersion (mechanical mixing). Higher flow velocities typically cause greater mixing and increased transport of suspended and bedload sediments. Relevant processes that influence sediment transport include deposition, erosion/resuspension, mixed-layer turbation, long-term burial, and ingestion/uptake by biota. The relative significance of these transport and fate mechanisms varies by contaminant, depending on physical/chemical properties specific to each contaminant. A potentially important mass transfer mechanism is surface sediment resuspension and movement of contaminants from bedded sediment to the water column with a resultant increase in mobility and bioavailability. Degradation processes relevant for transformation and degradation of contaminants in the study area include oxidation/reduction, hydrolysis, dehalogenation, volatilization (primarily from dissolved phase in surface water), and photolysis (primarily in upper levels of surface water). Biodegradation involves the metabolic oxidation or reduction of organic compounds and is carried out predominantly by bacteria in aqueous environments.

Finally, a number of processes govern how organisms living in the study area are exposed to contaminants and how contaminants are transformed, excreted, or stored in tissue. Organisms living in the study area may bioaccumulate contaminants through physical, chemical, and biological processes, including transfer of water-borne contaminants across gill structures or other tissues, ingestion of sediment, or consumption of prey, which may increase relative tissue concentrations at progressively higher trophic levels in the food chain. Contaminant burden in body tissues is mediated through growth, reproduction, excretion, metabolic transformation, or sequestration.

10.1.5   Human and Ecological Receptors, Exposure Pathways, and Summary of Site Risks

People interact with the river in a number of ways. Portland Harbor is a major industrial water corridor and working harbor, and the majority of the study area waterfront is currently zoned for industrial land use (City of Portland 2006b). The study area also contains some natural areas and provides recreational opportunities, both on the water and along the riverbanks, including boat ramps, beaches, and waterfront parks. Recreational and subsistence fishing is conducted in the lower Willamette River

basin, including the study area, both by boaters and from shore. The extent to which commercial fishing occurs within the study area is not known, but it is presumed to be negligible. For Native American anglers, the Willamette River provides a ceremonial and subsistence fishery for Pacific lamprey and spring Chinook salmon. There is also documented evidence of transients camping along the river for extended periods of time.

Currently or potentially exposed populations were identified based on consideration of both current and potential future uses of the study area, and include populations who may be exposed to contamination though a variety of activities. The specific populations and exposure pathways evaluated were:

- Dockside workers—Direct exposure via incidental ingestion and dermal contact with beach sediments.

- In-water workers—Direct exposure to in-water sediment.

- Transients—Direct exposure to beach sediment, surface water for bathing and drinking water scenarios, and groundwater seeps.

- Recreational beach users—Direct exposure to beach sediment and surface water while swimming.

- Tribal fishers—Direct exposure to beach or in-water sediments, and consumption of migratory and resident fish.

- Recreational and subsistence fishers—Direct exposure to beach or in-water sediments, consumption of resident fish, and consumption of shellfish.

- Divers—Direct exposure to in-water sediment and surface water.

- Domestic water user—Direct exposure to untreated surface water potentially used as a drinking water source in the future.

- Infants—Consumption of human breast milk.

The presence of uncertainty is inherent in the risk assessment process, and USEPA policy calls for numerical risk estimates to always be accompanied by descriptive information regarding the uncertainties of each step in the risk assessment to ensure an objective and balanced characterization of the true risks and hazards. Additionally, it is important to note that the risks presented here are based on numerous conservative assumptions in order to be protective of human health and to ensure that the risks presented are more likely to be overestimated rather than underestimated. A detailed analysis of the uncertainties associated with the BHHRA is found in Section 6 of Appendix F.

The major findings of the BHHRA are:

- Estimated cancer risks resulting from the consumption of fish or shellfish are generally orders of magnitude higher than risk resulting from direct contact with sediment and surface water. Risks and noncancer hazards from fish and shellfish consumption exceed the USEPA point of departure for cancer risk of 1×10^{-4} and target HI of 1 when evaluated on a harbor-wide basis, and when evaluated on the smaller spatial scale by river mile. Consumption of resident fish species consistently results in the greatest risk estimates. Evaluated harbor-wide, the estimated RME cancer risks are 4×10^{-3} and 1×10^{-2} for recreational and subsistence fishers, respectively.

- Noncancer hazard estimates for consumption of resident fish species are greater than 1 at all river miles. Based on a harbor-wide evaluation of noncancer risk, the estimated RME HI is 300 and 1,000 for recreational and subsistence fisher, respectively. The highest hazard estimates for recreational fishers are at RM 4, RM 7, RM 11, and in Swan Island Lagoon.

  The highest noncancer hazards are associated with nursing infants whose mothers consume resident fish from Portland Harbor. When resident fish consumption is evaluated on a harbor-wide basis, the estimated RME HI is 4,000 and 10,000 for breastfed infants of recreational and subsistence fishers, respectively. Evaluated on a harbor-wide scale, the estimated RME HI for tribal consumers of migratory and resident fish is 600 assuming fillet-only consumption, and 800 assuming whole-body consumption. The corresponding HI estimates for nursing infants of mothers, who consume fish, are 8,000 and 9,000 respectively, assuming maternal consumption of fillet or whole-body fish.

- PCBs are the primary contributor to risk from fish consumption harbor-wide. When evaluated on a river mile scale, dioxins/furans are a secondary contributor to the overall risk and hazard estimates, particularly at RM 6 and 7. PCBs are the primary contributors to the noncancer hazard to nursing infants, primarily because of the bioaccumulative properties of PCBs and the susceptibility of infants to the developmental effects associated with exposure to PCBs.

Ecological habitat is affected by the fact that the majority of the study area is industrialized, with modified shoreline and nearshore areas (e.g., wharfs, piers extending out toward the channel, bulkheads, and riprap-armored banks). The federal navigation channel has less habitat diversity than the shallow, nearshore areas, but this is consistent with river systems generally. Some segments of the study area are more complex, with small embayments, shallow water areas, gently sloped beaches, localized small wood accumulations, and less shoreline development, providing some habitat for a suite of local fauna. Riparian, shallow-water, and vegetated habitats are limited to the nearshore area or shoreline, and are much less extensive.

Organisms that use the lower Willamette River include invertebrates, fishes, birds, mammals, amphibians, reptiles, and aquatic plants. Each group contributes to the ecological function of the river based on trophic level, abundance, biomass, and

interaction with the physical-chemical environment and other species. The lower Willamette River is an important migration corridor for anadromous fish, such as salmon and lamprey, and provides habitat for numerous resident fish species (more than 40 species have been collected in many historical and recent studies) that represent four feeding guilds: herbivores/omnivores, invertivores (either from the water column or bottom habitats), piscivores, and detritivores.

Habitat in the study area is limited for aquatic-dependent mammals because of past human modification of riparian habitats. The upland environment near the lower Willamette River is primarily urban, with fragmented areas of riparian forest, wetlands, and associated upland forests. Numerous aquatic and shorebird species, such as cormorants and spotted sandpipers, use the habitats, where available, in the study area.

The following complete and significant exposure pathways were quantitatively evaluated in the BERA using multiple lines of evidence:

- **Benthic invertebrates**—Direct contact with sediment and surface water, ingestion of biota and sediment, and direct contact with shallow TZW

- **Fish**—Direct contact with surface water, direct contact with sediment (for benthic fish receptors), ingestion of biota, incidental ingestion of sediment, and direct contact with shallow TZW (for benthic fish receptors)

- **Birds and mammals**—Ingestion of biota and incidental ingestion of sediment

- **Amphibians and aquatic plants**—Direct contact with surface water and shallow TZW.

The following presents the primary conclusions of the BERA:

- In total, 93 contaminants (as individual contaminants, sums, or totals) pose potentially unacceptable ecological risk. The list can be condensed if individual PCB, DDx, and PAH compounds or groups are condensed into three comprehensive groups: total PCBs, total DDx, and total PAHs. Doing so reduces the number of contaminants posing potentially unacceptable risks to 66.

- Risks to benthic invertebrates are clustered in 17 benthic areas of concern.

- Sediment and TZW samples with the highest HQs for many contaminants also tend to be clustered in areas with the greatest benthic invertebrate toxicity.

- COPCs in sediment that are most commonly spatially associated with locations of potentially unacceptable risk to the benthic community or populations are PAHs and DDx compounds.

- The most ecologically significant contaminants are PCBs, PAHs, dioxins and furans (as TEQ), and DDT and its metabolites. PAHs and DDx risks are largely limited to benthic invertebrates and other sediment-associated receptors. PCBs tend to pose their largest ecological risks to mammals and birds.

- The combined toxicity of dioxins/furans and dioxin-like PCBs, expressed as total TEQ, poses the potential risk of reduced reproductive success in mink, river otter, spotted sandpiper, bald eagle, and osprey. The PCB TEQ fraction of the total TEQ is responsible for the majority of total TEQ exposure, but the total dioxin/furan TEQ fraction also exceeds its TRV in some locations of the study area.

10.2   CHEMICAL-SPECIFIC CONCEPTUAL SITE MODELS

The CSMs for the 13 indicator contaminants are presented in the following sections. Each discussion includes a brief presentation of contaminant distribution; potential sources and pathways; and loading, fate, and transport. For each CSM, a three-section panel series is provided that presents cross-media contaminant distributions and available source information and presents a subset of the contaminant distribution data. An electronic version of the three-section CSM panels is included in Appendix I.

Panel A presents summary information on the observed concentrations in surface sediment (using Thiessen polygons to spatially represent concentrations between data points), sediment traps, riparian soil/sediment, surface water, and TZW from RM 1.9 to 11.8, excluding dredge and cap sample locations. A histogram of the surface sediment data is included in the top left-hand corner of each panel to show the distribution of the data. Unfiltered push probe, filtered push probe, and peeper results are displayed for TZW. Surface water XAD data are presented for total PCBs, dioxins/furans, total DDx, total PAHs, total chlordanes, aldrin, and dieldrin. Surface water peristaltic pump data are presented for arsenic, chromium, copper, zinc, and TBT. The BEHP data presented are a combination of the XAD and peristaltic pump data.

Panel B presents a summary of subsurface sediment concentrations and large-scale (>30 cm) erosional/depositional areas predicted for a major flood based on the FS HST model for the study area (Chen 2011, pers. comm.). Thiessen polygons on these panels represent concentrations in the sediment interval just below the surface sediment (typically the B interval). A histogram of the subsurface sediment data is included in the top left-hand corner of each panel. Also included are icons depicting the locations of 10 major types of historical industries that are or were active in the study area.

In addition to the erosional/depositional information shown on Panel B, Map 10.2-1 shows areas in the study area at risk for surface sediment disturbance from incidental anthropogenic activities based on water depth and in-water operations. This includes all areas above the –5 ft NAVD88 contour that are potentially subject to boat wakes, areas in the immediate vicinity of docks and berths, and any additional areas where sediment scour that did not appear to be due to natural forces was evident in the 2002–2009 bathymetric time-series data set.[3] This map does not include an analysis of those

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[3] Map 10.2-1 is a qualitative presentation of areas where there is a reason to believe that anthropogenic disturbance risk may be relatively higher than other areas.

activities that are specifically intended to move sediments (shoreline/structure construction, maintenance dredging, or remedial capping/dredging).

Panel C presents whole-body concentrations in field-collected smallmouth bass, clams, crayfish, and sculpin. A detailed view of the composite groupings can be found on Map 2.1-7a–d.

For each upland site that has undergone sufficient investigation to identify known or likely complete pathways, a box is shown on the panels listing the applicable pathways and noting whether they are complete or likely complete. Where there are insufficient data to make a determination or when a complete pathway was determined to be not present (see Tables 10.2-1through 10.2-13), no information is presented.

> **Commented [KK1]:** Remove all footnotes to all tables that do not apply to the table.

Along with the panels, three figures are provided for each CSM chemical to portray loading, fate, and transport processes under current conditions in the study area.[4] The first figure consists of a set of box and whisker plots—an initial plot comparing the range of the estimated external and internal annual loads to the study area for each of the loading terms quantified for a given CSM contaminant, followed by a pair of plots comparing the concentrations of the chemical in surface sediment, sediment traps, and suspended solids in surface water for the entire study area. The second figure is a box-and-arrow diagram[5] depicting relevant loading, fate, and transport processes for each CSM chemical at the study area scale. The third figure provides a graphical comparison, by river mile, of the quantified external and internal loading terms, including central, upper, and lower estimates, and affords additional resolution of spatial patterns in loading to the study area.

As documented in Section 6.1 and Appendix E, external loading of each CSM contaminant to the study area was estimated quantitatively for upstream surface water,[6] stormwater, atmospheric deposition to the water surface, and groundwater advection through subsurface sediments. Quantitative estimates were also generated for upland groundwater plumes and permitted point-source discharges for a subset of the CSM contaminants for which these terms may be significant. Unquantified loading terms, including bedload, volatilization, and riverbank erosion, are represented qualitatively on the box-and-arrow diagrams. The only contaminant fate and transport mechanism internal to the study area for which quantitative estimates were developed in the RI is pore water advection from surface sediment to the overlying surface water column.

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[4] Includes surface water and bedded sediments in the surface mixed layer (0–40 cm bml).

[5] This diagram does not attempt a mass balance because sufficient data are not available and because of the varying levels of quantification (qualitative to quantitative) of each term.

[6] As discussed in Section 6.1, estimated upstream surface water loads were developed using data from both RM 11 and RM 16. Because of the complex hydrodynamics on the lower Willamette River between its confluence with the Columbia River (RM 0) and the entrance to Multnomah Channel at RM 3 (frequent flow reversals, see Section 3.1.4.3), surface water chemical loads leaving the Study Area at RM 1.9 could not be estimated using the simplified approach described in Section 6.1. The furthest downstream surface water loads for the lower Willamette River were estimated at RM 4. Surface water loads exiting the Study Area via Multnomah Channel were also estimated.

Other internal fate and transport mechanisms, including sediment erosion, sediment deposition, sediment burial, and biological and geochemical transformation (degradation) are represented qualitatively on the box-and-arrow diagrams.

10.2.1   Total PCBs

The study area graphical CSM for PCBs is presented on Panels 10.2-1A–C. PCBs are a class of nonpolar, synthetic, halogenated hydrocarbons that were manufactured in the United States between 1929 and 1977 and widely used for a variety of purposes. Current allowed uses include transformers, heat transfer systems, natural gas pipelines, existing carbonless copy paper, and electrical switches. Historical PCB uses included dielectric fluids in transformers and capacitors, electrical cables, cutting oils, hydraulic oils, lubricants, heat transfer fluids, plasticizers, flame retardants, additives to pesticides, paints, carbonless copy paper, caulk, adhesives, sealants, in heat transfer systems, electromagnets, and for dust suppression. PCB sources in waste materials include scrap metal recycling, auto salvage, used oil, recycled paper, asphalt roofing materials, building demolition, and in the repair and salvaging of ships, locomotives, heavy equipment, and manufacturing equipment. Although PCBs are ubiquitous in the environment, commercial PCB production in the United States ended in 1977. Consequently, most of the mass of PCBs found in the study area sediments is primarily derived from historical sources. In addition, secondary sources may introduce PCBs to the lower Willamette River through a variety of environmental pathways as described in Section 10.2.1.2

Although PCBs do degrade in the environment (e.g., by reductive dehalogenation), they are persistent. PCBs are hydrophobic/lipophilic organic substances that accumulate in organisms both by uptake from the environment over time (bioaccumulation) and along the food chain (Erickson 1997). PCBs biomagnify with each trophic level in the food web (biomagnification). In aquatic organisms, the rate and physiological mechanism of PCB metabolism depend on the species and the specific type of PCB.

10.2.1.1   Total PCBs Contaminant Distribution

On a harbor-wide basis, the highest PCB sediment concentrations occur in nearshore areas and in locations proximal to local upland sources (Maps 5.2-3a-hh and Panels 10.2-1A–B). Relatively high concentrations of PCBs are also often found in riparian sediments, sediment trap samples, surface waters, and biota samples in the areas with elevated sediment concentrations.

Similar spatial and concentration trends are observed in subsurface sediments (Panel 10.2-1B). Areas where surface and subsurface concentrations are not well correlated may be an indication of spatially and temporally variable inputs and sources, or to different influences from sediment transport mechanisms. Areas where the highest concentrations of PCBs in sediment are observed include RM 11.3E, RM 8.8-10W, Swan Island Lagoon, International Slip (RM 3.7-3.8E), RM 2.1-2.5E, and RM 4.0–4.1E. Total PCBs concentrations are generally higher in subsurface sediments

10-17

(Panels 10.2-1A–B, Maps 5.2-3a-hh, and Figure 5.2-3), pointing to predominantly historical total PCBs sources and higher past loads.

Exceptions to the pattern of higher concentrations at depth are found at RM 11.3E, in Willamette Cove, and in Swan Island Lagoon. PCB concentrations in the area of RM 11.3 are greater in surface than subsurface samples along the eastern nearshore area and adjacent channel edge. The nearshore sediment PCB distribution, as well as the collocated surface water and sediment trap data, indicate a local, recent input and/or redistribution of PCBs historically released into this area and present in the sediments. Anthropogenic sediment disturbance in this area also may have altered the distribution of PCBs with depth in the sediment column and re-exposed and re-mobilized subsurface contamination.

Collocated surface and subsurface samples from the inner portion of Willamette Cove also exhibit higher surface PCB concentrations than at depth, which may be indicative of higher recent inputs. Finally, in Swan Island Lagoon, mean surface and subsurface total PCBs concentrations are approximately the same. The lack of a vertical gradient may reflect a combination of time-varying inputs, low net sedimentation rates, and localized high surface sediment mixing rates that result in variable spatial trends in sediment quality with depth.

Relatively high concentrations of PCBs in surface water are generally found in areas with elevated sediment concentrations. The highest total PCB concentrations were associated with single-point samples in Willamette Cove and at RM 5.5. Total PCB concentrations at RM 11 were consistently higher than at RM 16, suggesting a source or sources between these locations. Aside from these exceptions, the range of total PCB concentrations within the study aea surface water was fairly consistent.

Total PCB congener concentrations in the study area sediment trap samples were 1- to 5-fold greater than upstream concentrations. These trends were also reflected in the Aroclor data. Downstream total PCB concentrations are similar to concentrations observed in Multnomah Channel and the upriver reach. The concentrations entering the site, at least in the western nearshore region, are similar in concentration to the upriver sediment traps for the time periods measured. However, the concentrations entering the eastern nearshore region sediments may be more influenced by sources immediately upriver in the downtown reach.

The highest concentrations of PCBs in the study area were typically found in biota samples from areas with high sediment concentrations, for example RM 2.2E to 2.4E, International Slip, RM 4.0E to 4.1E, Willamette Cove, Swan Island Lagoon, and near OF 44 and OF 43 near RM 11.2E.

Spatial variations in PCB composition (based on congener data) are evident throughout the study area, and areas of elevated PCB sediment concentrations often exhibit congener homolog patterns that are distinct from surrounding areas of lower PCB concentrations (Appendix D1, Maps D1.5-1 and D1.5-2; Figures D1.5-2a-c and D1.5-

3a-c). PCB homolog patterns in surface and subsurface sediment, sediment traps, and in the particulate portion of the surface water samples, are often similar within each area. Subsurface sediment patterns are less consistent with surface sediment homolog patterns for the areas at RM 6.9 to 7.5W and RM 2.1 to 2.5E when compared other contaminated locations.

Relatively low concentrations of PCBs are widespread in portions of the harbor away from the localized areas of elevated concentrations (Panel 10.2-1A and Map 5.2-2). The homolog patterns in these widespread, low level PCB areas are generally similar in both depositional and erosional areas, have less distinct variations than areas of higher concentration, and may reflect inputs from upstream and transport within the study area.

10.2.1.2 Potential PCB Sources and Pathways

Numerous upland sites have been identified as being known or likely historical and/or current sources of PCBs. These sites discharge directly to the river or discharge through shared conveyance systems (Table 4.4-3). Historical and current known or likely complete pathways for PCBs in stormwater have been identified at several properties associated with former shipyards and sites where transformers were serviced and/or dismantled. Historical wastewater discharges associated with ship building and decommissioning, electrical component manufacturing, and leaks and spills from equipment that used fluids that may have contained PCBs are likely, but have not been specifically identified or quantified. Wastewater discharges are currently regulated primarily through NPDES permits.

Potential upland and overwater sources and identified known and likely complete migration pathways are identified on Table 10.2-1 and Panels 10.2-1A–C. These sources and pathways, identified on the basis of the process described in Section 4.2, focus on ECSI sites and are based on a review of information in the associated DEQ ECSI files and other readily available site information, including, in the case of LWG-member sites, information provided by the site owner.

The most significant migration pathways for PCBs in the study area are historical and included industrial wastewater, stormwater, overland transport, overwater releases, and riverbank erosion (Table 10.2-1). Atmospheric deposition and upstream inputs may have also contributed PCBs to the study area; the releases from these pathways are not quantifiable and are difficult to distinguish.

Stormwater PCB loads have decreased substantially from historical levels since implementation of stormwater controls and the statutory ban on PCB manufacture in the 1970s. Overland transport was likely more important prior to the development of extensive stormwater conveyance systems. Bank erosion is also likely more important when PCBs were in wider use, or when contaminated material was used in construction fill activities. Historical PCB overwater releases have not been identified through the file review process, but are likely to have occurred in association with overwater operations, such as ship building and dismantling, ship repair and maintenance, and

with the use of hydraulic fluids in dock operations. The locations of elevated PCB concentrations in sediments coincide in some cases with ship construction, dismantling, and repair operations, and it is likely that overwater releases occurred concurrently as a result of historical activities in these locations. PCBs are also detected in sediments near outfalls draining facilities historically engaged in electrical equipment manufacturing, such as at RM 11.3E and at OF-17. Stormwater discharges and riverbank erosion associated with fill soil from offsite and/or steel manufacturing activities at RM 2E have also resulted in PCB contamination in sediments.

Current PCB inputs to the study area are lower than historical inputs. However, measured elevated levels of PCB concentrations in surface sediments and other media, including biota in the International Slip and Swan Island Lagoon, indicate ongoing localized inputs and/or internal mass transfer of historical PCB inventory from subsurface to surface sediments and then to other media by processes such as sediment resuspension (due to both natural and anthropogenic disturbance factors) and biological uptake. While surface sediments generally exhibit lower PCB concentrations than subsurface sediments, the temporal persistence of elevated PCB levels in surface sediments in many nearshore and off-channel areas suggests that net sedimentation rates may be low in many nearshore areas. This is supported by the bathymetric change data and the limited radioisotope data from the study area (Anchor 2005b); sediment column mixing rates are high, and inputs of PCBs still occur. Potentially important current pathways include stormwater and riverbank erosion. The effects of current releases and these physical site features are expressed in surface sediment concentrations (Panel 10.2-1A).

Known or likely complete historical pathways for PCBs have been identified at 40 sites, and include stormwater (38 sites), overland transport and riverbank erosion (6 sites), and overwater releases (1 site). Current known or likely complete pathways for PCBs have been identified at 18 sites, and include stormwater (16 sites), overland transport (2 sites), riverbank erosion (3 sites), and groundwater transport (1 site). Historical and current sources are presented in Table 10.2-1 and Panels 10.2-1A–C.

10.2.1.3 Loading, Fate, and Transport of PCBs

PCB loading, fate, and transport in a typical year for the study area is summarized on Figures 10.2-1a-b, 10.2-2, and 10.2-3. Estimates are for current conditions and likely differed historically. Much of the PCB mass in the study area, especially in deeper sediments, is attributable to historical loading that occurred under different loading conditions and rates.

Upstream surface water represents the largest estimated current loading term for PCBs to the study area (Figures 10.2-1a and 10.2-2), and is associated with both the dissolved and suspended fractions. On an annually averaged basis, the majority of this load occurs during low-flow conditions (Figure 6.1-2), which exist for approximately two-thirds of the year. Surface water samples collected during high-flow consistently exhibited lower concentrations of PCBs than in low-flow samples, indicating that

inflow concentrations at high flow rates have greater influence than local effects. Total PCB concentrations in sediments accumulating in upstream borrow pits, which are likely a mixture of upstream bedload and suspended load, are comparable to the upriver bedded sediment background concentrations.

PCB loads in surface water increase between the upstream and downstream boundaries of the study area in both the particulate and dissolved fractions, and is in part attributable to quantified external loads (stormwater, atmospheric deposition, and advection through subsurface sediments). Other possible reasons for the increased loading are due to internal fate and transport processes such as sediment resuspension, which have not been quantified. The distribution of total PCBs in surface sediments, sediment trap samples, and the particulate fraction of surface water samples, on both a dry-weight and OC-normalized basis, is presented on Figure 10.2-1b.

Estimates of current PCB loading via stormwater are approximately half the estimated upstream load, atmospheric deposition directly to the study area river surface is nearly an order of magnitude lower than the upstream surface water load (Figure 10.2-2). PCBs were detected in stormwater in Round 3A and 3B sampling in each land use area sampled (see Section 6.1.2.3). Groundwater advection through subsurface sediments is estimated the least significant of the quantified terms, but is subject to a relatively high degree of uncertainty due to the variability in published organic-carbon partitioning values for PCBs. As discussed in Section 6.1.1.2, bedload into- and out of the study area is expected to be low relative to dissolved and particulate surface water loading. PCB volatilization from the water column is relevant for only a small fraction of the less chlorinated PCB congeners and is also expected to be low.

Fate and transport processes internal to the study area for total PCBs are shown on Figure 10.2-2. PCB transport to the water column due to pore water advection through surface sediments is the only process for which quantitative estimates were developed, and is estimated to be similar in magnitude to the subsurface advective loading. Other internal fate and transport processes are depicted on Figure 10.2-2 on a qualitative basis only. Sediment erosion, deposition, and burial are a function of locally and temporally variable hydrodynamic conditions and the surface sediment mixing rate. PCB partitioning between suspended sediment and surface water depends on the relative concentrations associated with suspended particulate organic carbon and the dissolved surface water fraction, as well as reaction kinetics. The fate of PCBs within the study area may also be influenced by relatively slow microbially facilitated degradation and photolysis.

PCB loads from upland groundwater plumes are not expected to be significant and estimates were not generated. Loading from permitted point source discharges were not estimated because PCBs are not regulated and monitored under any active discharge permits within the study area. Estimates of PCB loading from upland soil and riverbank erosion also were not assessed due to a paucity of data for riparian soil PCB concentrations and erosion rates.

The load of total PCBs in surface water increases downstream through the study area to RM 4[7] (Figure 10.2-3); the largest PCB stormwater inputs enter the study area between RM 3 and 4. As described in Section 6.1.2, the estimated load (1 kg/yr) to this reach is largely from a non-representative (unique) site (Outfall WR-384) and exceeds the next highest stormwater load, between RM 8 and 9, by a factor of 10.

Atmospheric deposition is estimated to contribute a total PCB load approximately one-third that of stormwater at the study area scale. Deposition loading to the water surface varies only as a function of water surface area by river mile.

No current known or likely complete PCB overwater pathways have been identified. Current overwater releases may be locally important at sites with continuous waste handling or operational activities, but are considered a minor current pathway overall.

While areas of PCB contamination in the study area appear to be the result of releases from specific localized sources, PCBs also enter the study area from non-point and diffuse sources such as private and public stormwater and sewer outfalls, and sources upstream of the study area in the Willamette River. Harbor-wide loading estimates indicate that the highest current external inputs to the study area are from upstream surface water and, to a lesser degree, stormwater runoff and atmospheric deposition. These estimates indicate that the mass flux of PCBs in surface water exiting the study area at RM 2 and at the Multnomah Channel entrance exceed the estimated fluxes entering the study area from all quantified external loading terms. This indicates an internal mass transfer of PCBs from bedded sediment to the water column, likely through sediment resuspension.

10.2.1.4 Human and Ecological Risks Associated with PCBs

PCBs are a primary contributor to human health risks at Portland Harbor, primarily through consumption of resident fish, and to breast-fed infants whose mothers have been exposed to PCBs. Total PCBs were identified as one of the primary contaminants that pose ecologically significant risks to mink, river otter, and spotted sandpiper, and low risk to osprey, bald eagle, sculpin, and multiple fish species. Total PCBs pose risks to ecological receptors through more lines of evidence than did any other contaminants evaluated in the BERA. They were also identified as one of the primary contaminants in sediment contributing to potentially unacceptable risk to the benthic community.

10.2.2 Total PCDD/Fs

A graphical CSM for total PCDD/Fs in the study area is presented Panels 10.2-2A–C. As a group, PCDDs represent 75 different isomers, while PCDFs comprise over 135 compounds (Eisler 1986). These two chemical classes are generally referred to as dioxins and furans, respectively. PCDD/Fs are byproducts of combustion, incineration, certain industrial chemistry processes, and natural sources, including combustion, metal

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[7] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.4.3).

smelting, and production of bleached paper, polyvinyl chloride, inks/dyes, certain chlorine production technologies, chlorophenols, chlorinated herbicides, and commercial Aroclor (PCB) mixtures (ATSDR 1998). Examples of combustion and incineration that may lead to the formation of PCDD/Fs include hazardous or medical waste incinerators, cement kilns, boilers and industrial furnaces, vehicle emissions, fossil fuel power plants, burning PCB-containing electrical equipment (such as transformers), and backyard burning (e.g., refuse piles, burn barrels). PCDD/Fs are naturally produced from forest fires, volcanic eruptions, and sedimentary deposits. Currently the largest source is from backyard burning (USEPA 2006n). When released into the air, some PCDD/Fs may be transported long distances, even around the globe. In the atmosphere, it has been estimated that 20 to 60 percent of 2,3,7,8-TCDD is in the vapor phase. Sunlight and atmospheric chemicals can break down a very small portion of the PCDD/Fs, but most PCDD/Fs will be deposited on land or water (ATSDR 1998).

Behavior of PCDD/Fs in the environment is characterized by low vapor pressures, high octanol-water and organic carbon partitioning coefficients (K_{ow} and K_{oc}, respectively), and extremely low water solubilities. They are hydrophobic and have a strong affinity for sediments with high organic matter content; as a result, transport of PCDD/Fs in aquatic systems is closely tied to fine-grained sediment transport processes. Some PCDD/Fs, present near the water surface and not bound to solids, may be subject to photodegradation (USEPA 1994). In general, PCDD/Fs are stable in all environmental media, with persistence measured in decades. Chemical degradation of PCDD/Fs through reductive dechlorination can also occur, but it is typically a slow process. PCDD/Fs have been shown to biomagnify in aquatic food webs and associated avian and mammalian species (ATSDR 1998).

10.2.2.1 Total PCDD/F Contaminant Distribution

Panels 10.2-2A–C present the study area graphical CSM for total PCDD/F. Care should be taken in interpreting Panels 10.2-2A–B because relatively few sediment samples were analyzed for PCDD/Fs. Total PCDD/Fs were detected in sediments in several locations along the eastern and western nearshore zones and in Swan Island Lagoon. The highest detected concentrations were found in the eastern nearshore zone at RM 2E-8E, Swan Island Lagoon, RM 11E, RM 6W-10.3W, from RM 4W-6W, and at RM 3.4W. There are a number of distinct locations scattered throughout the study area that exhibit elevated PCDD/F concentrations in sediment and coincide with currently identified known or likely historical industrial dioxin and/or furan sources, including RM 11E, Swan Island Lagoon, Willamette Cove, and between RM 6.5W and 7.5W, adjacent to Arkema and Rhone-Poulenc. Total PCDD/F concentrations in the subsurface are generally greater than that observed in surface sediments. The higher concentrations observed in subsurface sediment relative to concentrations in surface sediment are indicative of a primarily historical input of these contaminants to the study area. Areas of apparent PCDD/F contamination in sediment in other locations in the study area not associated with documented sources and pathways indicate that all point sources may not have been identified. However, these locations are coincident with areas exhibiting higher concentrations of other indicator contaminants, such as PCBs

and/or PAHs. While the relatively low density of PCDD/F data makes surface to subsurface concentration gradients difficult to discern on a study area-wide basis, there does not appear to be strong trends with depth.

Surface water concentrations are elevated in Willamette Cove, at RM 6.8W, and in the RM 4 transect sample. Total PCDD/F surface water concentrations within the study area did not display any consistent trends from upstream to downstream.

There are no strong spatial or temporal gradients evident in total PCDD/F concentrations measured in suspended sediments collected in sediment traps within the study area (Figure 5.3-3a-b). In general, study area sediment trap samples had higher total PCDD/F concentrations than the upstream locations near RM 15.6.

PCDD/Fs were detected in all fish and invertebrate tissue samples collected from the study area, with the highest concentrations observed in samples collected between RM 6.5 and 7.5 (Panel 10.2-2C).

10.2.2.2 Potential PCDD/Fs Sources and Pathways

Historical known complete or likely complete pathways for PCDD/Fs have been identified at four sites (Table 10.2-2 and Panels 10.2-2A–C) and include stormwater (four sites), groundwater (one site), overwater releases (one site), overland transport (two sites), and riverbank erosion (two sites).

Current known complete or likely complete pathways for PCDD/Fs have been identified at two sites and include stormwater (both sites), overland transport (one site), and riverbank erosion (one site). Stormwater transport is expected to be the most significant current pathway for PCDD/Fs to enter the study area from adjacent upland sites. Gould Electronics, Rhone Poulenc, and McCormick and Baxter are identified as having known complete historical pathways.

No current known or likely PCDD/F overwater pathways have been identified. However, McCormick and Baxter is identified as having a known historical pathway.

No sites have been identified as having current known or likely complete groundwater pathways for PCDD/Fs, though McCormick and Baxter had a historical complete pathway, the potential for migration in the past is known to have existed at McCormick and Baxter.

10.2.2.3 Loading, Fate, and Transport of PCDD/Fs

The loading, fate, and transport assessment for total PCDD/Fs is summarized on Figures 10.2-4a-b, 10.2-5, and 10.2-6. The greater PCDD/Fs mass in the study area deeper sediments (Panel 10.2-2B) is likely attributable to historical loading that occurred under different past loading conditions and rates. Due to the limited data available, PCDD/F loading terms were quantified only for upstream surface water and advection through subsurface sediments. Upstream loading contributes much greater

estimated loads of total PCDD/Fs to the study area than advection through subsurface sediments (Figures 10.2-4a and 10.2-5). Upstream surface water loads are associated primarily with the suspended particulate fraction, with similar total PCDD/F mass loads entering the study area during high-flow and low-flow conditions (see Figure 6.1-4). The total PCDD/F upstream loads in surface water are comparable with downstream loads. A cross-media comparison and statistical assessment of surface sediment, sediment trap samples, and the particulate fraction of surface water samples on a study area-wide basis is shown in Tables 10.2-14a-b and Figure 10.2-4b. An apparent increase in the estimated surface water flux of PCDD/Fs from upstream to downstream within the study area may reflect contributions from a combination of other external loading terms (stormwater, advective transport, and atmospheric deposition) or internal fate and transport processes, such as sediment resuspension.

10.2.2.4 Human and Ecological Risks Associated with PCDD/Fs

Dioxins and furans pose unacceptable risks to human health at Portland Harbor, primarily due to exposures through consumption of shellfish and resident fish, as well as a direct contact exposure to contaminated sediments for people engaged in fishing activities. They were identified as one of the primary contaminants that pose ecologically significant risks. Dioxins and furans pose an ecologically significant risk to mink, spotted sandpiper, osprey, and bald eagles. They are also contributors to the overall risk to river otters.

10.2.3 DDx

The graphical CSM for DDx compounds is presented in Panels 10.2-3A–C, and loading information is summarized in Figures 10.2-7a-b through 10.2-9.

DDT was widely used as an insecticide from about 1943 (Porter 1962) until 1972, when it was banned for most uses in the United States, because of its toxicity to wildlife. DDE and DDD are the primary metabolites of DDT, but technical-grade DDT may also contain DDE and DDD as impurities (ATSDR 2002a). DDT was released historically to air and soil through widespread spraying of crops and forests, and for mosquito control. Releases also occurred at more local scales at pesticide manufacturing and storage facilities. Ongoing releases occur in countries where its use is not banned, and some of these releases can be transported globally through the atmosphere. Because DDT is no longer produced or sold in the United States, significant new releases to the environment are uncommon. Consequently, most of the mass of DDx found in the study area is derived from historical sources. However, DDx compounds continue to be introduced to the lower Willamette River through a variety of environmental pathways, as described in Section 10.2.3.2.

DDT degrades slowly via abiotic and microbially-mediated processes to the more persistent DDx compounds, DDE (under aerobic conditions) and DDD (in anoxic systems; USEPA 2000b). In the environment, DDx compounds are persistent and are readily bioaccumulated in aquatic organisms (USEPA 2000b). While there is no clear evidence that DDT, DDD, or DDE causes cancer in humans, there is sufficient evidence

of carcinogenicity of these substances in rodents, which has led to their classification as probable human carcinogens (ATSDR 2002a).

10.2.3.1 DDx Contaminant Distribution

Within the study area, the highest DDx concentrations in sediments are limited to localized areas in nearshore zones. The highest reported concentrations in sediment are located in the western nearshore zone between RM 6W and 7.5W, and are proximal to known upland sources. Other areas of elevated total DDx sediment concentrations are smaller in extent and are located at RM 8.8W, at the mouth of Swan Island Lagoon, and in subsurface sediments only at RM 4.8W and the head of the International Slip.

The concentrations of DDx in surface sediments are greater in the study area than in the upriver, downtown, Multnomah Channel, and downstream reaches. When DDx concentrations are averaged on a river-mile basis, the greatest difference between surface and subsurface sediment concentrations is observed in the western nearshore zone between RM 7 and 8, where the highest concentrations are found at depths greater than 10 ft (Figures 5.2-10 and 5.2-11; Panels 10.2-3A–B), indicating greater past loads. DDx concentrations found downstream of RM 8 are typically in the 5 to 100 µg/kg range. Upstream of this location concentrations are typically less than 5 µg/kg.

DDx compounds are widely detected in Portland Harbor surface and subsurface sediments; other abiotic media, such as surface water, sediment traps, and TZW; and fish and shellfish tissues. The highest DDx concentrations are found in several nearshore areas associated with known historical DDx sources (Arkema, Rhone Poulenc, and Willbridge Terminal) along the western shore of the river from about RM 6.8 to RM 7.5. Throughout the study area, DDx concentrations are generally lower in surface than subsurface sediment, indicating greater historical inputs or past releases.

The highest DDx concentrations observed in surface water, sediment traps, TZW, and biota samples are from the area of RM 6.8 to 7.5. Sediment concentration gradients along this western nearshore area and in the edge of the navigation channel downstream from this source area indicate the downstream transport of DDx in sediments and possible inputs from other point sources. This pattern is consistent with the hydrodynamic and sediment transport characteristics in this portion of the study area, particularly from RM 5 to 7. Less extensive areas with elevated DDx occur at Gunderson, at the head of International Slip, RM 4.8W (subsurface only), and at the Cascade General Shipyard at depth in the sediment column.

DDx concentrations in surface water transect samples collected at the upstream end of the study area and upriver (Panel 10.2-3A) in high-flow conditions (Figure 5.4-20) are indicative of inputs from upriver areas. The results of single-point samples collected downstream of RM 7.5 and the transect at RM 6.3 exhibit elevated DDx concentrations in both low-flow and high-flow conditions (Figure 5.4-20; Panel 10.2-3A). Results of surface water samples collected at RM 2 do not exhibit elevated concentrations, although results from the surface water transect at the mouth of Multnomah Channel

exhibited elevated total DDx concentration during low-flow conditions (Panel 10.2-3A; Figure 5.4-20). The DDx concentrations were higher in unfiltered samples than in filtered samples. Combined with the low aqueous solubility of DDx compounds, this indicates that DDx is more associated with solids.

DDx concentrations in the sediment trap samples were generally low throughout most of the study area, although higher concentrations were measured in traps at RM 6 and 7.5W and in Swan Island Lagoon in the summer and fall periods. The elevated DDx concentrations reported at RM 11E in the fall period are likely an artifact resulting from analytical interferences associated with PCBs also detected in that sample.

Elevated DDx concentrations were observed in TZW samples collected near RM 7.2W. TZW samples from other areas were not analyzed for DDx, precluding comparisons with other areas. As stated above with respect to surface water, the TZW DDx concentrations were higher in unfiltered samples than in filtered samples.

The highest concentrations of DDx in biota are found where sediment concentrations are highest, and most extensive near RM 7 (Figure 5.6-4a-e; Panel 10.2-3C).

10.2.3.2 Potential DDx Sources and Pathways

Within Portland Harbor, DDx was historically associated with pesticide manufacturing and storage facilities. It also was released to air and soil through widespread spraying of crops and forests, and for mosquito control throughout the Willamette River Basin. Some riverbank facilities and other upland properties likely applied DDT for mosquito control before it was banned. Known historical chemical manufacturing and/or storage sites are presented on Map 3.2-14, and include Arkema, Rhone Poulenc, and the Shell Terminal at Willbridge. As shown on Table 10.2-3 and Panels 10.2-3A–C, historical known complete or likely complete pathways for DDx have been identified at four sites. Of these, the groundwater pathway is included at two sites, stormwater at four sites, and riverbank erosion at two sites. Historical known complete or likely complete pathways for DDx were not identified for overwater releases or overland runoff. Currently known complete or likely complete pathways for DDx have been identified at three sites and include groundwater migration, stormwater, and riverbank erosion at one site. No current known complete or likely complete pathways were identified for overwater releases or overland runoff.

Areas of DDx contamination are found downstream of RM 7, and may be related, in part, to downstream transport of sediment in the relatively higher energy areas that extend from about RM 7 to 5 (see Section 3.1.5.2.6). DDx concentrations observed in other upstream and downstream areas are not associated with known sources (Panels 10.2-3A–B).

Historical DDx sources to the study area included upstream surface water, stormwater, and riverbank erosion (Table 10.2-3). The historical releases from these pathways are not quantifiable. Overall, current DDx inputs to the study area are much lower than

historical inputs because DDT is no longer manufactured or used in widespread spraying applications and because waste management practices have greatly improved. However, elevated DDx concentrations in surface sediments and in other media, including biota, at RM 6.8 to 7.5W, and at RM 8.8W indicate localized, external inputs or ongoing internal mass transfer of historical DDx from subsurface/surface sediments to other media by processes such as sediment resuspension and biological uptake.

The most significant current influx of DDx to the study area is upstream surface water, while stormwater transport is the most significant current pathway to the study area from adjacent upland sites. DDx was detected in stormwater from each land use area sampled. Outfalls associated with the heavy industrial land use category and selected individual non-representative outfalls contributed the majority of the estimated DDx stormwater load (see Section 6.1.2.3). Current and/or historical known or likely complete pathways for DDx in stormwater have been identified at sites including Arkema, Rhone Poulenc, Metro Central Transfer Station, the Shell facility at the Willbridge Terminal, and City of Portland Outfall OF-22B. Most of the facilities either drain stormwater or infiltrate contaminated groundwater to shared conveyances (e.g., Saltzman Creek and OF-22B). Source control measures taken at the Arkema site have largely eliminated the stormwater pathway from this site. No potentially complete current or historical overland transport pathways or historical overwater releases of DDx have been identified for any sites.

Known or likely historical DDx groundwater pathways have been identified at Arkema and Rhone Poulenc. Cleanup efforts conducted by Rhone Poulenc are expected to eliminate the preferential groundwater pathway to stormwater. DDx is present in upland groundwater plumes at the Arkema site, and it has been detected in nearshore wells. Groundwater controls at the Arkema site have greatly reduced the groundwater pathway.

Contaminated riverbanks that are known or likely complete historical DDx erosion pathways have been identified at Arkema and Willbridge Cove. At Arkema, the riverbank area received fill that included miscellaneous materials from spent chlorine cells for several years (ERM 2005). The fill material included clean soil. In addition, dredge spoils were deposited on the riverbank. Riverbank erosion at the site has also been identified as a known complete current pathway for DDx. The riverbank in Willbridge Cove may have been contaminated by the deposition of sediment containing DDx, and is subject to erosion.

10.2.3.3 Loading, Fate, and Transport of DDx

Total DDx loading, fate, and transport assessment for the study area in a typical year is summarized on Figures 10.2-7a-b through 10.2-9. Estimates are for current conditions, and likely differed historically. Much of the total DDx mass in the study area, especially in deeper sediments, is attributable to historical loading that occurred under different loading conditions and rates.

Historical DDx sources to the study area included upstream surface water, stormwater, and riverbank erosion (Table 10.2-3). The most significant current influx of DDx to the study area is upstream surface water, and is associated with both the dissolved and suspended particulate fraction. The majority of the mass load enters the study area during high-flow conditions (Figure 6.1-6), indicating that erosion of upstream agricultural areas is an important upstream source. While additional DDx mass also enters and remains in the study area with upstream bedload sediments, it has not been quantified. Total DDx loads in upstream surface water (RM 11) and the downstream boundary of the study area (combined loads at RM 2 and the Multnomah Channel entrance) are comparable. Additional DDx loading sources, in order of importance, are stormwater[8], atmospheric deposition to the river surface (atmospheric deposition to the watershed is included in the stormwater term), groundwater advection through subsurface sediments, and upland groundwater plume discharge.

Internal DDx fate and transport for the study area is shown on Figure 10.2-8. DDx transport to the water column due to pore water advection through surface sediments is the only process for which quantitative estimates were developed. Other internal fate and transport processes are depicted on Figure 10.2-8 on a qualitative basis only. DDx partitioning between suspended sediment and surface water depends on the relative chemical concentrations associated with suspended particulate organic carbon and the dissolved surface water fraction, as well as reaction kinetics.

DDx loads from permitted non-stormwater point source discharges are not expected to be significant and estimates were not generated.[9] Estimates of DDx loading from upland soil and riverbank erosion also were not assessed in the RI due to a paucity of data for riparian soil DDx concentrations and erosion rates.

Total DDx load in surface water increases moving downstream through the study area (Figure 10.2-9), with the largest DDx stormwater inputs entering between RM 6.8 and 7.4. Upland groundwater plume loads are highest between RM 7 and 8. Estimated current DDx annual loads from advection through subsurface and surface sediments follow the patterns of DDx sediment concentrations (Figure 6.1-59), with the highest loads between RM 7 and 8.

Estimates of quantifiable external loading terms indicate that the highest current external inputs to the study area are from upstream surface water. Estimates of DDx fluxes in surface water at RM 2, the downstream end of the study area, and in Multnomah Channel suggest that slightly more DDx mass may be leaving the study area downstream in surface water than entering the study area from all quantified

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[8] The DDx stormwater loading term developed in the RI is dominated by the estimated load from a single "non-representative" site. As discussed in Section 6, the estimated loads from this non-representative site are subject to a high degree of uncertainty related to extrapolation of stormwater concentrations measured in the non-representative outfalls (<10 percent of the drainage sub-basin) to areas that are larger than the catchments that drain to the non-representative outfalls.

[9] NPDES permitted wastewater discharge is not expected to contain significant amounts of total DDx relative to other loading terms.

sources. This possible increase may reflect an internal mass transfer of DDx from bedded sediment to the water column, likely through sediment resuspension. The relationships between tissue body burdens and abiotic concentrations across the study area are a primary focus of the fate and transport modeling to be conducted at the Site for the FS.

10.2.3.4 Human and Ecological Risks Associated with DDx

DDD, DDE, and DDT pose unacceptable human health risks associated with consumption of resident fish, though this was largely limited to the area at RM 7W. Total DDx was identified as one of the primary contaminants that pose ecologically significant risks. It poses potentially unacceptable risk primarily to benthic invertebrates and sediment-associated receptors. DDx compounds in sediment pose potentially unacceptable risk to the benthic community only on the western side of the river between approximately RM 6.8 and 7.4.

10.2.4 Total PAHs

The graphical CSM for PAHs is shown on Panels 10.2-4A–C. PAHs are a large chemical group composed of more than 100 chemicals that are constituents of crude and refined oil, shale oil, coal tar, and creosote. PAHs are also formed during the incomplete combustion of organic materials including coal, oil, gas, wood (wood stoves, fireplaces), garbage (municipal waste incineration), or other organic substances, such as tobacco. Natural sources of PAHs include volcanoes and forest fires. The largest historical sources of the high concentrations of PAHs in study area sediments were localized releases, such as historical industrial direct discharges, from facilities along the study area that formerly or currently use, manufacture, and/or store products and waste materials containing PAHs (petroleum oils and coal-based products, petroleum product use and storage, used oil, and asphalt roofing materials).

PAHs may accumulate in benthic organisms, fish, and other organisms that ingest sediments while feeding. However, biomagnification through the food chain is expected to be minimal as fish, mammals, and birds all possess the ability to metabolize PAH compounds.

10.2.4.1 Total PAH Contaminant Distribution

PAHs are present at a wide range of concentrations throughout the study area in all media. On a harbor-wide basis, the highest PAH concentrations in sediments generally occur downstream of RM 7 in nearshore areas proximal to local upland sources (Maps 5.2-16 and 5.2-17a-hh; Panels 10.2-4A–B) offshore of Siltronic, Gasco, Marine Finance, and Foss Brix. Elevated PAH concentrations are also observed in surface and subsurface sediments in the navigation channel between RM 4 and 6.5. Other areas of elevated total PAH concentrations in surface sediments include Mar Com South (RM 5.5–5.6E), Terminal 4 Slip 3 and Wheeler Bay (RM 4.3–4.6E), Slip 1 (RM 4.3E), and the International Slip (RM 3.7–3.8E). The portion of the study area upstream of RM 7 (not including Swan Island Lagoon) is characterized by widespread total PAH

concentrations less than 500 µg/kg. In contrast, downstream of RM 7 and away from
the high concentration areas associated with known sources, and also in Swan Island
Lagoon, total PAHs concentrations are generally 1,000–5,000 µg/kg.

Total PAH concentrations are generally higher in subsurface sediments within the study
area as a whole (Panel 10.2-4A–B; Maps 5.2-17a-hh; Figure 5.2-15), pointing to higher
historical inputs to the study area. The most notable exception to this pattern is the
navigation channel at RM 5 to 6.5 where the total PAH concentrations in surface
sediment are greater (Maps 5.2-17k-m), indicating downstream transport of PAHs in
surface sediments once they reach the channel from adjacent or upstream nearshore
zones. This is consistent with the relative dynamic channel environment found from
RM 5 to 7 (see Section 3.1.5.2.6). Other exceptions to the general pattern of higher
subsurface total PAHs include Swan Island Lagoon and Multnomah Channel, where
higher PAH concentrations are observed in the upper portion of the sediment column
and not just the surface layer.

PAH compositions in sediment trap and high-flow surface water particulate samples
were generally similar to that of the sediments, indicative of increased bedded sediment
resuspension during higher flow periods. PAH composition in sediment trap and
surface water samples during low-flow and stormwater-influenced sampling events
generally did not correlate well, indicating that current, lateral and upstream sources
differ in composition from the PAHs in the bedded sediments. Total PAH
concentrations in surface water are elevated predominately during low-flow conditions
(Figure 5.4-24), further illustrating the localized nature of the PAH sources in the study
area. Total PAH concentrations in sediment trap samples are notably elevated at
RM 6W in all seasons sampled (Figure 5.3-6a-b). Less distinct spikes were measured
from May to August in Swan Island Lagoon, and from August to November in
Multnomah Channel.

Total PAH concentrations in TZW were reported in areas that correspond with elevated
areas of sediment concentrations. The highest concentrations reported in biota samples
also correspond with areas where total PAH concentrations in sediment are elevated.

10.2.4.2 Potential PAH Sources and Pathways

PAHs are associated with bulk fuel storage, MGP, ship and automobile scrapping,
asphalt roof manufacturing, use of lubricants, hydraulic, and fuel oils in a large number
of industrial and commercial operations, and leaks from vehicles and machinery.

Known complete or likely complete historical pathways for PAHs have been identified
at 56 sites, and include stormwater (48 sites), groundwater (11 sites), overwater releases
(21 sites), overland transport (10 sites), and riverbank erosion (14 sites). Current known
complete or likely complete pathways for PAHs have been identified at 30 sites and
include stormwater (16 sites), groundwater (9 sites), overwater releases (14 sites),
overland transport (3 sites), and riverbank erosion (4 sites). This information is
summarized in Table 10.2-4 and on Panels 10.2-4A–C. Known or likely current and

historical upland sources that correlate with areas of high concentrations in sediment include the former MGP site at Gasco, dry dock operations at Cascade General in Swan Island Lagoon, the International Slip, Mar Com, bulk fuel terminals at ARCO, ExxonMobil, and Kinder Morgan, and historical releases from McCormick and Baxter in Willamette Cove. Based on reported PAH concentrations in sediment near outfalls draining facilities, it is also likely that stormwater/wastewater/overland transport releases occurred concurrently at Burgard Industrial Park (WR-123), Siltronic and Gasco (OF-22C), and Greenway Recycling, PGE-Forest Park, Willbridge Terminal, Front Avenue LP, and Chevron Asphalt (OF-19). Because wastewater discharges in CSO areas are regulated through municipal pretreatment permits, PAHs are not identified as a COI at any sites with a pretreatment permit (see Table 4.4-7).

Current known and likely complete pathways for migration of PAHs in groundwater have been identified at nine facilities, most of which are associated with bulk fuel storage (Table 10.2-4). Overwater releases are likely to have occurred in association with overwater operations, such as fuel transfers and spills, drydock and berth operations, overwater maintenance operations, vessel servicing and emissions, ship repair and maintenance activities, direct discharges of PAH contaminants (tar, oil) to the river, releases during product loading/unloading at docks, and tug and barge operations.

Known complete groundwater pathways were identified at the Siltronic and Gasco sites. Potentially complete groundwater migration pathways were identified at Willbridge Terminal, Kinder Morgan Linnton, ARCO, and ExxonMobil. However, results from TZW samples collected offshore of these four sites indicate that the role, if any, of groundwater transport of PAHs is minor and is not significantly influencing TZW and sediment chemistry.

Bank erosion likely played a bigger role historically as well, particularly during construction in places where contaminated sediments or manufacturing material and debris from upland activities were used as fill. Based on limited riverbank sampling, riverbank erosion is a historical known or likely complete pathway for PAHs at 13 sites: Crawford, Gasco, Gunderson, Mar Com South Parcel, Marine Finance, Port of Portland Terminal 4, Slip 1 and Slip 3, Premier Edible Oils, Siltronic, Sulzer Bingham, Triangle Park property, Willamette Cove, and the Willbridge Terminal facility.

10.2.4.3 Loading, Fate, and Transport of PAHs

Total PAH loading, fate, and transport in the study area in a typical year are summarized on Figures 10.2-10a-b, 10.2-11a, and 10.2-12, relative loads for LPAHs and HPAHs are presented on Figures 10.2-11b and 10.2-11c, respectively. While these loading estimates are for current conditions, much of the total PAH mass in the study area is attributable to historical loading.

Advection through subsurface sediments, upstream surface water, and upland groundwater plumes is estimated to contribute comparable (within an order of magnitude) total PAH loads to the study area (Figures 10.2-10a and 10.2-11a).

Estimated external PAH loads associated with stormwater, atmospheric deposition to the river, and direct discharges from permitted non-stormwater point sources are 1 to 2 orders of magnitude lower than the other external terms. LPAHs contribute the bulk of the total PAH load for all loading terms evaluated quantitatively (Figures 10.2-11b and 10.2-11c). The majority of the total PAH mass load from upstream surface water enters the study area during high-flow conditions (Figure 6.1-8). Upstream surface water total PAH and LPAH loads are associated primarily with the dissolved fraction, whereas HPAH loads are slightly higher in the particulate than in the dissolved fraction. Total PAH load in surface water increases moving downstream through the study area, particularly downstream of RM 7, in both the particulate and dissolved fractions (Figure 10.2-12) under all flow conditions. PAH loading terms that were assessed qualitatively are also shown on Figures 10.2-11a–c. PAH volatilization from the water column may be significant for LPAHs, although this was not evaluated.

Fate and transport processes internal to the study area for total PAHs, LPAHs, and HPAHs are also shown on Figures 10.2-11a, 10.2-11b, and 10.2-11c, respectively. Quantitative estimates were developed only for transport to the water column due to pore water advection through surface sediments, and this term is lower in magnitude than the subsurface advective loading term for total PAHs and LPAHs, and similar in magnitude for HPAHs. Estimates of PAH loading from upland soil and riverbank erosion were not assessed due to a paucity of data for riparian soil PAH concentrations and erosion rates.

The total PAH load in surface water increases moving downstream through the study area,[10] particularly downstream of RM 7 (Figure 10.2-12). Most of the load from the two largest external lateral loading terms, subsurface sediment advection and upland groundwater plumes, enters the study area between RM 6 and 7.

PAH contamination in sediments is associated with known or likely historical and current sources. Two areas of elevated total PAH concentrations, offshore of the Gasco former MGP site at RM 6.5W and the Port's Terminal 4, Slip 3, are the focus of early cleanup actions independent of the harborwide RI/FS. Releases associated with Gasco and other known and potential sources along the west side of the river between RM 6 and 7 have resulted in higher nearshore total PAH concentrations in both surface and subsurface sediments. Downstream concentration gradients, both nearshore and in the navigation channel, in this relatively high-energy portion of the river indicate downstream transport of PAHs extending approximately to the Multnomah Channel entrance. In the navigation channel from RM 5 to 6, high surface sediment concentrations relative to subsurface levels are indicative of the transport of material through this reach rather than long-term accumulation. Other, less extensive areas of PAH sediment contamination in the study area, are associated with known or likely sources, including offshore of Cascade General, in Willamette Cove (subsurface

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[10] At approximately RM 3, the Columbia River and Multnomah Channel hydraulically influence the flow regime complicating interpretation of load conditions in this area (see Section 3.1.4.3).

sediments), offshore of Mar Com, at the head of the International Slip, and at several nearshore locations along the west bank from RM 3 to 5.

In general, total PAH concentrations in subsurface sediment are greater than in surface sediment, indicating greater inputs or releases historically that have been reduced or eliminated over time. Elevated total PAH levels in other media—TZW, surface water, sediment traps, and biota (particularly clams)—are largely restricted to the most extensive area of elevated sediment concentrations, along the western shore around RM 6.

Overall, current PAH inputs to the study area are much lower than historical inputs because material handling and waste management practices have greatly improved. Measured elevated concentrations of PAHs in surface sediments and other media including surface water (e.g., Swan Island Lagoon, RM 7.4W, RM 6.8W) and biota in specific areas (e.g., International Slip; Terminal 4, Slips 1 and 3; offshore of Gasco; and Swan Island Lagoon) indicate that localized inputs and/or internal mass transfer of sediment PAHs by processes such as sediment resuspension likely affect other media. Potentially important current pathways from upland sources include groundwater plumes, overwater releases, overland transport, and riverbank erosion.

Empirical estimates of current external PAH loads (mass/yr) to the study area indicate that advection through subsurface sediments, upstream surface water, and upland groundwater plumes contribute comparable total PAH loads to the study area, whereas loads associated with stormwater, direct atmospheric deposition to the river, and direct discharges from permitted non-stormwater point sources are considerably less important. These data indicate that surface water PAH mass loads increase from upstream to downstream, likely reflecting inputs from the other external loading terms, which peak at RM 6 to 6.9. Internal mass transfer from bedded surface sediments to surface water/biota from sediment resuspension erosion was not quantified but likely also contributes to this pattern.

10.2.4.4 Human and Ecological Risks Associated with PAHs

PAHs were estimated to pose unacceptable risks to human health based on fish and shellfish consumption and direct contact with sediment exposures, generally limited to the area of RM 4W to 6W. PAHs were identified as one of the primary contaminants that pose ecologically significant benthic risks. As a group, PAHs are associated with the benthic risk areas from RM 5.1 to 6.9 on the west side of the river. Within this area, some PAH concentrations observed in TZW and surface water samples pose localized potentially unacceptable risks to fish, invertebrates, amphibians, and aquatic plants. Risks to aquatic-dependent birds and mammals are negligible.

10.2.5 Bis(2-ethylhexyl)phthalate

A graphical CSM for BEHP in the study area is presented on Panels 10.2-5A–C. Phthalates are manufactured, colorless liquids with little to no odor. The primary sources of phthalate emissions are the industries that manufacture it or use it in

production, such as the chemical industry, the plastics industry, the cosmetic industry, machinery manufacturers, and manufacturers of plywood and millwork. Phthalates are commonly added to plastics and paint to make the finished product more flexible (ATSDR 2002b) and are widely used as plasticizers in polyvinyl chloride resin. In addition, phthalates are common components of detergents and carriers in pesticide formulations (Xie et al. 2005). Releases to the environment can occur as direct spills from industrial facilities that manufacture or use these chemicals. More commonly, releases occur by leaching of low volumes of phthalates from the wide variety of products that contain them (ATSDR 2002b). Despite its low vapor pressure, BEHP is ubiquitous in the atmosphere due to its widespread use in plastics. BEHP, which is present in the atmosphere in both the vapor phase and associated with particulates, is subject to both wet (rain and snow) and dry (wind and settling) deposition on the earth's surface (ATSDR 2002b).

The behavior of BEHP in the study area environment is largely defined by its high hydrophobicity (the central estimate of log K_{oc} is 7.4). Due to this hydrophobicity, BEHP has a strong tendency to sorb to solids and organic matter in surface water and in sediment-pore water environments. As such, it is not expected to migrate significantly in groundwater. Because of its low vapor pressure, volatilization is a minor loss mechanism for BEHP, particularly when sorbed to solids. BEHP is subject to fairly rapid degradation in the atmosphere, but much slower abiotic and microbially-mediated degradation processes under aerobic conditions in sediment and surface water (HSDB 2006; ATSDR 2002b). Its physical properties indicate that BEHP would be expected to bioconcentrate in aquatic organisms; however, study area biota results suggest that BEHP is readily metabolized.

10.2.5.1 BEHP Contaminant Distribution

Elevated BEHP concentrations in sediments were reported, with minor exceptions, in nearshore areas outside the navigation channel and proximal to local upland sources (Maps 5.2-20a-o and Panels 10.2-5A–B). Elevated concentrations are observed in Swan Island Lagoon and in the International Slip (RM 3.7–3.8E), along the riverside of Schnitzer-Calbag site RM 3.8–4.1E, 7.6E, 7.6W, 8.3W, 8.8W, 9.7W, and offshore of RM 7.1 and 10 in the navigation channel. Elevated subsurface concentrations were less widespread, and typically observed in areas with elevated surface concentrations. Exceptions were noted at RM 10.5W and 5.7W.

Elevated concentrations of BEHP were detected in only one surface water sample collected during high-flow conditions, at RM 8.6W. BEHP concentrations in sediment trap samples did not vary widely spatially or temporally throughout and upstream of the study area, with the exception of notably elevated concentrations measured in the two samples (summer, fall) collected in Swan Island Lagoon (see Figure 5.3-7a-b).

Because of BEHP's hydrophobic nature, groundwater is unlikely to be a significant historical or current pathway for BEHP migration into the study area and was not

included in the TZW sampling program. Thus, no data exist to corroborate this hypothesis.

BEHP was detected in laboratory-exposed clams and worms, mussels, and fish. However, it was not detected in crayfish, juvenile Chinook, or carp. The highest reported concentrations in biota were generally detected on both sides of the river near RM 4 and above RM 9.5, and one location just off the downstream end of Swan Island. With the exception of the surface sediment on the east bank near RM 4 and subsurface sediment at the downstream end of Swan Island, elevated BEHP concentrations in biota do not correlate well with elevated concentrations in sediment.

10.2.5.2 Potential BEHP Sources and Pathways

Historical known complete or likely complete pathways include stormwater (28 sites), overwater releases (3 sites), overland runoff (1 site), riverbank erosion (2 sites), and groundwater (1 site) (Table 10.2-5). Current known complete or likely complete pathways for BEHP have been identified at 16 sites and include groundwater (3 sites), stormwater (12 sites), and overwater releases (2 sites).

BEHP concentrations are elevated in surface sediment in current and former shipyards such as Swan Island and the International Slip. BEHP is likely to have been released to Swan Island Lagoon and the Portland Shipyard for many years, and continued inputs may occur from known sources and contributions from the numerous outfalls in this area. The lack of elevated concentrations at depth in the sediment column in Swan Island Lagoon may indicate low burial rates, surface sediment mixing, and/or higher recent inputs. Higher concentrations in subsurface sediment near the shipyard docks indicate historically high levels and burial over time.

There are no known sources of BEHP associated with sites that discharge stormwater to the International Slip. However, this area has an auto shredding facility, and BEHP has been identified with metal scrapping (see Section 3.2.3.1.4). It was also the former location of a large shipyard owned by the Oregon Shipbuilding Corporation. Several metals facilities (either fabrication or scrapping) and a historical paint spill area have been identified as BEHP sources that discharge to OF-19 at RM 8.3W. Identified sources of BEHP at RM 8.8W include Gunderson (outfalls from the Marine Barge Paint and Blast Area) and multiple facilities discharging to OF-18.

BEHP migration by overland transport has been identified at the Mar Com South Parcel as a historical likely complete pathway. Current overwater releases may be locally important at sites with continuous waste handling or operational activities, but are considered a minor current pathway overall. Cascade General and Mar Com South represent the only currently known or likely complete BEHP overwater pathways. Groundwater discharge has been identified as a current or historical complete pathway at Premier Edible Oils, Triangle Park property, and the Willbridge Terminal facility. There are no known atmospheric sources of BEHP within the study area.

No upriver watershed sources of BEHP have been identified.

10.2.5.3 Loading, Fate, and Transport of BEHP

BEHP loading, fate, and transport assessment for the study area in a typical year is presented on Figures 10.2-13a through 10.2-15. The highest relative current external inputs are from upriver surface water,[11] with relatively minor additional contributions from study area stormwater and advection through subsurface sediments. The total BEHP loads in surface water upstream and at the downstream boundary of the study area are generally comparable. Although the current upstream surface water load estimate exceeds the other loading terms, there is no indication that the surface water load is responsible for spatial distribution of the BEHP observed in study area sediments, and much of the surface water load appears to pass through the Site. As noted, the off-channel and nearshore elevated BEHP concentrations appear to be associated with localized upland sources and pathways.

A cross-media comparison of surface sediment, sediment trap samples, and particulate suspended solids on a study area-wide basis (Tables 10.2-14a-b and Figure 10.2-13b) show that the mean BEHP concentrations differ across all media. The highest average concentrations were observed in surface sediment, followed by surface water particulates, and then sediment trap samples.

10.2.5.4 Human and Ecological Risks Associated with BEHP

BEHP poses a risk to human health for tribal fishers consuming both resident and migratory fish caught within Portland Harbor. It was identified as posing potentially unacceptable risk to invertebrates, fish, amphibians, and aquatic plants. However, based on the frequency of exceedances and generally low magnitude of ecological risks for all species except smallmouth bass and sculpin, negligible risks are expected.

10.2.6 Total Chlordanes

A graphical CSM for total chlordanes in the study area is presented on Panels 10.2-6A–C. Chlordane is a manufactured chemical that was used as a pesticide on crops, including corn and citrus, and on home lawns and gardens in the U.S. from 1948 to 1988. It was also used from the 1950s to the 1980s to prevent or eliminate termites. EPA banned all uses of chlordane with the exception of termite control in 1983; all uses were banned in 1988 (ATSDR 1995). Chlordanes are hydrophobic, and sorb to solids and organic matter in surface water and sediment. They are persistent in sediments, and subject to very slow abiotic degradation processes. The dissolved fraction in surface water is subject to volatilization. Chlordanes can bioaccumulate in the tissues of fish, birds, and mammals (ATSDR 1995).

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[11] The surface water data set only has total concentrations for BEHP; therefore, Figure 10.2-13a presents only the total estimated surface water loading rates for this chemical.

10.2.6.1 Total Chlordanes Contaminant Distribution

Total chlordanes are the sum of oxychlordane, *trans*-chlordane, *cis*-chlordane, *trans*-nonachlor, and *cis*-nonachlor. Each of these chemicals is analyzed individually and the concentrations are summed to obtain the total chlordanes value.

Several sediment, surface water, and biota samples were reported with high detection limits for total chlordanes (Panels 10.2-6A–C). These high detection limits are the result of chromatographic interferences, laboratory blank contamination, mass spectrometer details related to identification of the components of total chlordanes, or limited sample sizes. High detection limits may obscure the presence of total chlordanes at a concentration below the elevated detection limit, but a high detection limit does not imply the presence of the chemical.

On a harbor-wide basis, the highest detected concentrations of chlordane in sediments are restricted to small, widely scattered nearshore or off-channel areas, proximal to local upland sources (Maps 5.2-22 and 5.2-23a-o and Panels 10.2-6A–B). Areas where surface and subsurface sediment concentrations are greater than 10 µg/kg include RM 5.8W-9W, and approximately RM 3E, 4E, 5.5E, and 11E. Elevated surface and subsurface concentrations are also found in Swan Island Lagoon, RM 5.6, and International Slip along the eastern nearshore. Reported concentrations in sediment trap samples were typically low (<4 µg/kg), with no strong temporal or spatial patterns in the measured concentrations (Figure 5.3-8a-b). Total chlordanes were detected in a majority of surface water samples. Total chlordanes were detected at low concentrations with varying frequency in all fish and invertebrate samples.

10.2.6.2 Potential Sources and Pathways of Total Chlordanes

The known sources of total chlordanes to the study area are summarized in Table 10.2-6 and on Panels 10.2-6A–C. The former Rhone Poulenc pesticide manufacturing facility is the only source of chlordanes currently identified that historically discharged manufacturing waste and stormwater to the river at approximately RM 6.9, and site groundwater infiltrates to City of Portland outfall OF-22B. However, the distribution of total chlordanes in nearshore sediments is indicative that other sources may also be present.

Historical known pathways for stormwater exist at the Rhone Poulenc facility, including infiltration of contaminated groundwater into the storm system and the City of Portland outfalls, specifically OF-22B (RM 6.9W). Total chlordanes have been detected in upland soils at the former Rhone Poulenc property, and stormwater is a likely complete historical pathway. Historically, manufacturing wastes from Rhone Poulenc were discharged to Doane Lake, which occasionally discharged to the river via a historical drainage ditch from 1972 to 1980. This ditch entered the river near RM 6.9, an area with elevated surface and subsurface sediment total chlordanes concentrations. Currently, site stormwater is collected, treated, and discharged through WR-6, also located at RM 6.9W. No current known or likely complete overland transport pathways for total chlordanes have been identified.

Total chlordanes were detected in sediment samples collected during the PGE Willamette River Sediment Investigation, and chlordanes were likely used as a pesticide in the agricultural areas of the Willamette River watershed up until the late 1980s, so upriver sources continue to exist.

10.2.6.3 Loading, Fate, and Transport of Total Chlordanes

The loading, fate, and transport of total chlordanes in the study area in a typical year is summarized on Figures 10.2-16a through 10.2-18. Current external inputs are dominated by upriver surface water, with relatively minor additional contributions from study area stormwater, advection through subsurface sediments, and atmospheric deposition to the river surface. Upstream surface water loads for total chlordanes are comparable with the combined loads at RM 2 and the Multnomah Channel entrance in both the dissolved and particulate fractions. Although the current upstream surface water load estimate exceeds the other current loading terms, there is no indication that this load is responsible for the distribution of total chlordanes in study area sediments.

Cross-media comparisons of surface sediment, sediment traps, and suspended solids in surface water (Tables 10.2-14a-b and Figure 10.2-16b) show that the overall surface sediment concentrations are greater than those in surface water particulate and sediment trap samples. Surface water particulate and sediment trap concentrations are similar.

10.2.6.4 Human and Ecological Risks Associated with Chlordanes

Total chlordanes are estimated to pose a cancer risk greater than the lower end of USEPA's risk management range based on a harbor-wide consumption of resident fish at a subsistence level. Chlordanes in sediment were identified as posing potentially unacceptable risks to benthic invertebrates. They were not identified as posing potentially unacceptable risks to other ecological receptors.

10.2.7 Aldrin and Dieldrin

Graphical study area CSMs for aldrin and dieldrin are presented on Panels 10.2-7A–C and 10.2-8A–C, respectively. Aldrin and dieldrin are organochlorine insecticides with similar chemical structures, manufactured for agricultural use from the 1950s to 1987. From the 1950s until 1970, aldrin and dieldrin were widely used insecticides for crops and livestock. Peak production occurred in the mid-1960s. Aldrin/dieldrin ranked second—after DDT—among agricultural insecticides used in the U.S. in the 1960s (Jorgenson 2001). USEPA banned the use of aldrin and dieldrin in 1974, except to control termites. By 1987, USEPA banned all uses (ATSDR 2002c).

Aldrin and dieldrin are hydrophobic and have a strong tendency to sorb to solids and organic matter in surface water and sediment. Aldrin is subject to abiotic and microbially-mediated degradation processes as well as photolysis in surface water. Dieldrin degrades very slowly in the environment. Dieldrin can bioaccumulate, whereas aldrin does not as it is quickly metabolized to dieldrin in plants and animals (ATSDR 2002c).

10.2.7.1 Aldrin and Dieldrin Contaminant Distribution

A number of sediment, surface water, and biota samples were reported with high detection limits for aldrin or dieldrin (see data reports in Appendix A5 for more information). High detection limits may obscure the presence of aldrin or dieldrin at a concentration below the detection limit, but a high detection limit does not imply the presence of the chemical.

Aldrin and dieldrin contamination in sediment is generally restricted to small, widely scattered nearshore areas. Elevated concentrations were generally not detected in off-channel or navigation channel areas, with the exceptions of detections of dieldrin at RM 11.4E (which includes several samples nearshore and offshore with elevated concentrations) and the head of the International Slip (RM 3.7E). Surface and subsurface sediments results show elevated concentrations of aldrin and dieldrin at RM 6.8 to7.5W and RM 8.8W. Overall, aldrin concentrations are slightly higher in subsurface sediment, while dieldrin concentrations are generally higher in the surface sediments. Areas with high concentrations of aldrin and dieldrin are generally collocated.

Aldrin and dieldrin were detected both in particulate and dissolved surface water samples, with the dissolved fraction slightly to largely predominating, with a major exception at RM 6.9. Aldrin and dieldrin were infrequently detected in sediment trap samples, most frequently downstream of RM 8. Tissue concentrations of aldrin and dieldrin were generally less than 10 µg/kg, although higher dieldrin concentrations were observed in sculpin collected from RM 2E to 4E.

10.2.7.2 Potential Aldrin/Dieldrin Sources and Pathways

The known sources of aldrin and dieldrin are summarized in Tables 10.2-7 and 10.2-8, respectively. The only currently identified source of aldrin and dieldrin within the study area is the former Rhone Poulenc pesticide manufacturing facility that historically discharged manufacturing waste and stormwater to the river at approximately RM 6.9. Aldrin and dieldrin have been detected in upland soils at this site, and stormwater is a known complete current and historical pathway. However, based on the distribution of aldrin and dieldrin in nearshore sediments, other sources may be present.

Historically, manufacturing wastes from Rhone Poulenc were routed to Doane Lake, which occasionally discharged to the river via a drainage ditch near RM 6.9 from 1972 to 1980. Currently site stormwater is collected, treated, and discharged through WR-6, also located at RM 6.9W. No current known or likely complete overwater or riverbank erosion pathways for aldrin or dieldrin have been identified. Atmospheric deposition is a potential historical and current pathway, but has not been quantified.

Jorgenson (2001) lists Van Waters & Rogers (Univar), as a producer and/or distributor of aldrin and dieldrin. However, there is no information about releases to the environment from this facility.

10.2.7.3 Loading, Fate, and Transport of Aldrin and Dieldrin

The loading, fate, and transport assessment of aldrin in the study area for a typical year is summarized on Figures 10.2-19a through 10.2-21, and on Figures 10.2-22a through 10.2-24 for dieldrin. Upriver surface water is the largest estimated external loading term; surface water loading of dieldrin is approximately 50 times that of aldrin. Stormwater is the second highest estimated loading term, followed by atmospheric deposition to the river surface and advection through subsurface sediments. There is an apparent increase in aldrin loads in surface water between the upstream and downstream boundaries of the study area. Conversely, there is little apparent change in surface water dieldrin loads between upstream and downstream boundaries. Although the current upstream surface water load estimate exceeds the other loading terms, there is no indication that the surface water load is responsible for the spatial distribution of aldrin and dieldrin in study area sediments, and nearshore aldrin and dieldrin concentrations appear to be associated with localized upland sources and pathways.

Cross-media comparisons of surface sediments, sediment trap samples, and suspended solids in surface water for aldrin and dieldrin are provided in Tables 10.2-14a-b (summary statistics and statistical comparisons) and Figures 10.2-19b and 10.2-22b (box-whisker distribution plots). Aldrin surface sediment and sediment trap concentrations are not significantly different; concentrations in both of these media are greater than the concentration in surface water particles on a study area-wide basis. For dieldrin, study area-wide surface sediment concentrations are significantly greater than the concentrations in surface water particulates, but there appear to be no significant differences between sediment trap concentrations and sediments or surface water particulates.

10.2.7.4 Human and Ecological Risks Associated with Aldrin and Dieldrin

Dieldrin poses unacceptable human health risks based on consumption of resident fish on both a harbor-wide and localized scale. Dieldrin was identified as posing potentially unacceptable risk to benthic invertebrates. Aldrin, which is rapidly transformed into dieldrin by most fish and wildlife species, was identified as posing potentially unacceptable ecological risk to spotted sandpiper at a limited spatial extent.

10.2.8   Arsenic, Copper, and Zinc

Graphical study area-wide CSMs are presented for arsenic, copper, and zinc on Panels 10.2-9A–C, 10.2-10A–C, and 10.2-11A–C, respectively. All three metals are abundant elements in the earth's crust, and natural releases to environmental media can be significant.

Arsenic is a naturally occurring metal that is found widely in natural minerals, including realgar ($As_4S_{4(s)}$), orpiment ($As_2S_{3(s)}$), and arsenolite (As_2O_3; ATSDR 2005a). It occurs naturally in soil, water, and air as a result of mineral weathering, leaching, volcanic eruptions, and wind-blown dirt (ATSDR 2005a). Anthropogenic activities, including smelting, use in pesticides, combustion of wood and coal, waste incineration, and the

production and use of treated wood products that utilize soluble chromated copper arsenate (CCA), can also release arsenic into the air, soil, water, and sediments.

Arsenic is a redox-sensitive species, existing at the +3 and +5 oxidation states in aqueous environmental conditions. Under oxidizing conditions the As(V) species (H_3AsO_4, $H_2AsO_4^-$, $H_2AsO_4^-$, $HAsO_4^{2-}$, AsO_4^{3-}) predominate, while under reducing conditions the As(III) species (H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$, AsO_3^{3-}) predominate (EPRI 1984). Arsenic is generally highly soluble, with few mineral phases exerting controls on aqueous arsenic concentrations under typical environmental conditions. Arsenic sulfide minerals, such as orpiment and realgar, can be formed under reducing and acidic conditions. Although arsenic minerals are generally highly soluble, adsorption reactions to sediment/aquifer mineral grain surfaces frequently limit dissolved arsenic concentrations (Kabata-Pendias and Pendias 1992). Arsenic is particularly strongly adsorbed to iron oxide minerals, with the As(V) species having a greater affinity for the oxide surface than the As(III) species. Because arsenic is frequently present as an anion under typical environmental conditions, its sorption to oxide surfaces is favored at pH <9 (Stumm 1992).

In aquatic environments, bioaccumulation of arsenic occurs primarily in algae and lower invertebrates (ATSDR 2005a). Fish and shellfish can also accumulate arsenic, mainly in the exoskeleton of invertebrates and in the livers of fish. While biomagnification in aquatic food chains is not generally considered significant, predatory fish may biomagnify arsenic through the consumption of prey species (especially bottom dwellers) (ATSDR 2005a).

Copper is an abundant metal element in the earth's crust. Natural releases to environmental media can be significant. Mining operations, agriculture, wastewater sludge, municipal and industrial solid waste, and other industrial processes can also result in environmental releases of copper (ATSDR 2004).

Copper exists in four oxidation states: Cu^0, Cu^{+1}, Cu^{+2}, and Cu^{+3} (Eisler 1998). Of these oxidation states, the cupric ion (Cu^{+2}) is most likely to be present in water, though rarely as a free ion. As free ions, cupric ions are the most readily available and toxic inorganic species of copper. However, the cupric ions have a strong tendency to complex with or sorb to numerous compounds normally found in natural waters, including suspended solids surfaces and dissolved or particulate organic carbon. Such complexation reduces bioavailability to aquatic organisms (Eisler 1998; USEPA 2000c). The amount of the various copper compounds and complexes present in solution in freshwater depend on water pH, temperature, hardness, and alkalinity; concentrations of bicarbonate, sulfide, and organic ligands; size and density of suspended materials; and rates of coagulation and sedimentation of particulates. Up to 29 different species of copper can be present in aqueous solution in the pH range from 6 to 9. The majority of copper in freshwater from pH 6.0 to 9.3 is in the form of carbonate species ($CuHCO_3^+$, $CuCO_3$, $Cu[CO3]_2^{-2}$), which have low toxicity (Eisler 1998). Cupric ions account for less than 1 percent of the total dissolved copper in freshwater. Copper carbonate, cupric hydroxide, cupric

oxide, and cupric sulfide will precipitate from solution or form colloidal suspensions when excess cupric ions are present (Eisler 1998). The majority of copper released to surface waters settles out or sorbs to sediments (Eisler 1998). While copper can transform in response to environmental chemistry, it does not degrade.

Copper is taken up by aquatic organisms primarily through dietary exposure and is an essential micronutrient for animals as a component of a number of essential enzymes. Most organisms retain only a small proportion of the copper ingested with their diet. Copper bioconcentrates in aquatic organisms but does not bioaccumulate in mammals or biomagnify in aquatic food chains (USEPA 2000c).

Zinc is a common element in the earth's crust and is released to the environment from both natural and anthropogenic sources. Mining and metallurgical processing are the primary anthropogenic sources, along with use of commercial products such as fertilizers and wood preservatives that contain zinc (ATSDR 1997a). Zinc is also used in galvanizing steel and in soldering formulas.

In the environment, zinc occurs as a sulfide, oxide, or carbonate. In freshwater, zinc is most soluble at low pH and low alkalinity: 10 mg Zn/L of solution at pH 6 that declines to 6.5 mg Zn/L at pH 7, 0.65 mg Zn/L at pH 8, and 0.01 mg Zn/L at pH 9 (Eisler 1993). Zinc in the water column can partition to dissolved and particulate organic carbon. Water hardness (i.e., calcium concentration), pH, and metal speciation are important factors in controlling the water column concentrations of zinc because the divalent zinc ion is believed to be responsible for observed biological effects (USEPA 2000c). Because zinc ligands are soluble in neutral and acidic solutions, zinc is readily transported in most natural waters (Eisler 1993). However, most of the zinc introduced into aquatic environments eventually is partitioned into the sediments (Eisler 1993). Zinc release from sediments is enhanced under conditions of high dissolved oxygen, low salinity, and low pH (Eisler 1993). Zinc may change forms in the environment, but it does not degrade.

Zinc is an essential trace element for all living organisms. As a constituent of more than 200 metalloenzymes and other metabolic compounds, zinc ensures stability of biological molecules such as DNA and of biological structures such as membranes and ribosomes (Eisler 1993). Most studies reviewed contain data that suggest that zinc is not a highly mobile element in aquatic food webs, and there appears to be little evidence to support the general occurrence of biomagnification of zinc within marine or freshwater food webs (USEPA 2000c). Bioavailability of zinc in sediment is controlled by the acid-volatile sediment concentration.

10.2.8.1 Arsenic, Copper, and Zinc Contaminant Distribution

With the exception of a broad area of relatively elevated copper and zinc concentrations in the vicinity of Swan Island Lagoon and zinc at Terminal 4, Slip 3, elevated arsenic, copper, and zinc concentrations in surface and subsurface sediment are generally restricted to small, widely scattered nearshore areas. The similarity of surface and

subsurface concentrations in these areas suggests both recent and historical inputs of all three metals.

Total arsenic, copper, and zinc concentrations in surface water were generally consistent across the entire study area. Concentrations were generally higher in low-flow sampling events, and there is generally no relationship evident between elevated surface water and elevated surface sediment concentrations. Sediments collected in and upstream of the study area over the course of a year in sediment traps show little spatial or temporal trends in measured concentrations. The highest reported arsenic concentrations in TZW are located at the west side of the channel at RM 6.2–6.6, and the west bank at RM 7.7. However, there are no corresponding high arsenic concentrations in sediment. The highest copper and zinc concentrations in TZW were measured offshore of the Gasco and Siltronic sites in areas where no elevated surface sediment concentrations were reported. Arsenic, copper, and zinc were detected in nearly all fish and invertebrate species and tissues analyzed from within the study area.

10.2.8.2 Potential Sources of Arsenic, Copper, and Zinc

The areas of elevated sediment concentrations correspond to the locations of former shipyards, wood treatment facilities, metal recycling operations, pipe manufacturing facilities, metal plating operations, and marine repair facilities. Metals are also associated with some facilities where metal slag and sandblast grit were used as fill. The primary industries in Portland Harbor known to have handled, manufactured, or disposed of arsenic, copper, or zinc include pesticide manufacturing, shipbuilding/demolition and marine repair facilities, metals recycling, battery scrapping, wood treating, and MGP. However, a number of sites with known or likely complete pathways do not appear associated with proximal surface sediment contamination.

Known complete or likely complete historical pathways for arsenic, copper, and zinc have been identified at up to 46 sites.

Although one or more of these metals has been identified as a stormwater COI at sites that drain to a number of municipal and non-municipal shared conveyance systems, associated sediment concentrations are not present near all these outfalls (Tables 10.2-9 through 10.2-11).

Zinc is elevated in sediment in Balch Creek Cove, which is the discharge location for OF-16, OF-17, WR-258, and WR-235. Metals have not been identified as stormwater COIs at WR-258 (drains Fire Station 6) and WR-235 (Port of Portland Terminal 2). GE Decommissioning has a known historical and likely current complete stormwater pathway for zinc. Calbag-Nicolai and Galvanizers have likely historical and known current complete stormwater pathways for zinc. All three of these sites are located within the basins of these outfalls.

Arsenic, copper, and zinc concentrations are elevated in sediments offshore of the areas adjacent to Gunderson and the small cove adjacent to the Shaver Transportation and

Front Avenue LP properties. Gunderson has known complete pathways, both historical and current, for stormwater and overland transport, and Front Avenue LP has a historical known complete stormwater pathway for these metals. Two shared conveyance systems also drain to this area, OF-18 and OF-19. However, none of these metals are elevated in the cove that OF-18 discharges to, and only copper is elevated in the vicinity of the OF-19 discharge. Front Avenue LP has a historical likely complete pathway for copper in stormwater, and Chevron has a historical known complete pathway for copper in stormwater. Both of these sites drain, at least in part, to OF-19 (Table 10.2-10).

Elevated sediment concentrations of copper and zinc are present on the nearshore areas on the west side of Swan Island Lagoon and the north end of Swan Island. Cascade General, Swan Island Upland Facility, and Fred Devine are identified as having a likely historically complete stormwater pathway for copper and zinc. Single samples with elevated concentrations of zinc and copper are also present near OFM-1 and of zinc near OFM-2. Freightliner TMP and TMP2 drain to these basins and are identified as having a likely historically complete stormwater pathway for copper and zinc.

Stormwater and groundwater infiltration from sites draining to OF-22B and OF-22C (RM 6.8W) are the likely sources of elevated arsenic concentrations in surface sediment at this location. Stormwater has been identified as a historical and/or current known complete pathway at Rhone Poulenc, Metro Transfer Station, Schnitzer-Doane Lake, Gasco, Siltronic, and Gould, which drained to or have had groundwater infiltration to these outfalls.

TZW sampling results indicate that groundwater is not a significant source to sediments. Low subsurface sediment arsenic concentrations may reflect the dynamic setting of the Site—arsenic may be transported downstream before there is an opportunity for long-term burial. Downstream surface sediment concentrations are low, suggesting that if this is the case, the mass of arsenic being discharged is relatively low and is readily dispersed.

Overland transport has been identified as a likely complete historical pathway for both Mar Com parcels, as well as a likely complete current pathway for the North parcel. Elevated surface sediment concentrations are located offshore of the Mar Com facilities and surface water concentration immediately upstream appears to support stormwater as a pathway. Calbag Metals, adjacent to the International Slip, has been identified as having a known current and historical complete stormwater pathways for zinc and copper; Terminal 4 has a likely historical complete overland pathway for zinc.

Arsenic, copper, and zinc are associated with Marine Barge Paint and Blast Area operations at Gunderson and a known historical and current complete pathway for groundwater has been identified for arsenic at Gunderson.

Groundwater is a known or likely current and historically complete pathway for these metals for the Siltronic and Gasco sites. However, none of these metals is present at elevated concentrations in surface or subsurface sediment.

Five sites have been identified as having historical known complete pathways for copper and zinc: Gunderson, Cascade General, Swan Island Upland Facility, McCormick and Baxter, and Schnitzer-Calbag. McCormick and Baxter also has a historical complete pathway for arsenic. All but McCormick and Baxter have known or likely current complete overwater pathways. McCormick and Baxter is the only identified site with a known historical complete pathway for arsenic.

Based on limited riverbank sampling, relatively large areas of elevated metals concentrations in surface sediment are associated with sites with known or likely historical complete riverbank erosion pathways for arsenic, copper, and zinc. These sites include Gunderson, Willamette Cove, Mar Com South, and McCormick and Baxter. A current known or likely complete pathway for riverbank erosion is limited to Gunderson.

10.2.8.3 Loading, Fate, and Transport of Arsenic, Copper and Zinc

The loading, fate, and transport of arsenic in the study area is summarized on Figures 10.2-25a through 10.2-27. Copper is summarized on Figures 10.2-28a through 10.2-30, and zinc is summarized on Figures 10.2-31a through 10.2-33. Estimated loads from upriver surface water dominate the current loads for all three metals, frequently exceeding the other quantified external loading terms by 2 or more orders of magnitude. Upstream and downstream surface water arsenic loads are comparable. Estimated copper and zinc loads entering the study area are slightly higher than the loads leaving. The distribution of arsenic, copper, and zinc (respectively) in surface sediments, sediment trap samples, and the surface water particulate fraction are presented on Figures 10-2-25b, 10.2-28b, and 10.2-31b, summary statistics in each media are presented in Table 10.2-14a, and the results of cross-media statistical testing are provided Table 10.2-14b. For each of these metals, all the distributions in each medium are significantly different from each other. Concentrations of each metal in surface water suspended particles are greater than in sediment trap or surface sediments on a study area-wide basis. Based on median values, sediment trap concentrations are slighter greater overall than surface sediment concentrations for all three metals.

Although the current upstream surface water load estimate greatly exceeds the other current loading terms, there is no indication that this load is responsible for the spatial distribution of the concentrations of these metals observed in study area sediments.

10.2.8.4 Human and Ecological Risks Associated with Arsenic, Copper, and Zinc

Arsenic concentrations in sediment pose unacceptable human health risks due to consumption of fish and shellfish, direct exposure to in-water sediment, direct exposure to beach sediment, and use of the Willamette as a drinking water source. Potentially

unacceptable ecological risks from copper were identified for more lines of evidence than any other contaminant except for PCBs, and were identified for benthic invertebrates and multiple fish species, as well as for spotted sandpiper. Zinc was identified as posing potentially unacceptable risk to benthic invertebrates and localized risk to other benthic receptors. Arsenic was identified as posing low unacceptable risks to benthic invertebrates.

10.2.9   Chromium

The study area graphical CSM for chromium is presented on Panels 10.2-12A–C. Chromium is a naturally occurring element found in rocks, animals, plants, and soil. It can exist in several different forms in soil, sediment, water, and air. Chromium(III) occurs naturally in the environment but is also a product of industry. Chromium(0) is used for making steel. Chromium(III) and chromium(VI) forms are produced by the chemical industry and are used for chrome plating, the manufacture of dyes and pigments, leather tanning, and wood preserving. Smaller amounts are used in drilling muds, rust and corrosion inhibitors, textiles, and toner for copying machines (ATSDR 2008).

In the environment, chromium can be found in air, soil, and water. Chromium compounds will usually remain in the air for less than 10 days, depositing to the land and water, especially by wet deposition (ATSDR 2008). Most chromium in water binds to soil and other materials and is subsequently subject to sediment transport processes, though a small amount may dissolve in the water. It can easily change from one form to another in water and soil, depending on the conditions present (ATSDR 2008). The relation between Cr(III) and Cr(VI) in the environment is strongly dependent on pH and oxidative properties of the location, but in most cases the Cr(III) is the dominating species (Kotas and Stasicka 2000).

Although chromium(III) is required in trace amounts for sugar and lipid metabolism in humans and its deficiency may cause a disease called chromium deficiency, chromium(VI) is a toxin and a carcinogen (ATSDR 2008). Fish do not significantly accumulate chromium in their bodies from water (ATSDR 2008).

10.2.9.1   Chromium Contaminant Distribution

Areas of elevated chromium concentrations in surface and subsurface sediments in the study area all occur in a few, widely scattered nearshore areas and at the head of the International Slip. They are limited in spatial extent and include RM 2E, 4E, 6E, Swan Island Lagoon, 6W, 7W, and 9W. The distribution of concentrations in surface and subsurface sediments suggest both recent and historical sources.

Sediment trap samples show a uniform distribution of chromium levels seasonally and throughout and upstream of the study area (see Figure 5.3-12a-b). Most sediment trap samples fall between 30 and 40 mg/kg; the single highest value (60 mg/kg) was measured upstream of the study area at RM 15.7E during the May to August period.

Chromium was sampled offshore of sites between RM 6.2W and 7.6W. Elevated TZW concentrations (greater than 100 µg/L) were observed between RM 6.2W and 6.5W, offshore of the Gasco and Siltronic properties.

Chromium was detected in all fish and invertebrate species and tissues analyzed within the study area.

10.2.9.2 Potential Sources of Chromium and Pathways

In Portland Harbor, the primary industries known to have handled, manufactured, or disposed of chromium include the steel industry (EOSM), ship building/demolition and marine repair facilities (Gunderson, Cascade General, Mar Com), metal recycling (Schnitzer-Calbag, Calbag-Nicolai, Calbag Metals-Front Ave., and former operations at Schnitzer-Doane Lake), wood treating (McCormack and Baxter), and MGP sites (Gasco), and heavy oil facilities (bulk fuel and asphalt storage). Sodium bichromate was used in the sodium chlorate manufacturing process as a corrosion inhibitor at Arkema. Historical known complete or likely complete pathways for chromium have been identified at 43 sites (Table 10.2-12 and Panels 10.2-12A–C), and include stormwater (38 sites), groundwater (7 sites), overwater releases (5 sites), overland transport (9 sites), and riverbank erosion (10 sites). Current known complete or likely complete pathways for chromium have been identified at 20 sites and include stormwater (13 sites), groundwater (5 sites), overwater releases (4 sites), overland transport (3 sites), and riverbank erosion (3 sites).

Groundwater is a historical known or likely complete pathway for chromium at seven sites and a current pathway for five sites. Chromium concentrations near OF-22B and OF-22C may be related to sites with known or likely complete groundwater/stormwater infiltration draining to these outfalls.

Based on limited riverbank sampling, riverbank erosion is a historical known or likely complete pathway for chromium at 10 sites, and a current source at 4 sites. Chromium concentrations in sediment are indicative of potential releases at EOSM, Schnitzer-Calbag metals, Portland Shipyards, and Gunderson.

Chromium was identified as a COI at 17 upstream sites based on their hazardous substances/waste types. Of these 17 sites, chromium was detected in sampled media at the following 5 sites:

- Willamette Falls Locks—Chromium detected in upland soil, and direct releases/spills represent potential pathways to the river

- Zidell Marine Corporation—Chromium detected in upland soil, and direct releases/spills, groundwater, and stormwater represent potential pathways to the river

- OHSU-Moody Ave. Units A, B, C—Chromium detected in upland soils, and stormwater and groundwater represent potential pathways to the river

- Clackamette Cove Area—Chromium detected in upland soils, and groundwater represents a potential pathway to the river

- South Waterfront Redevelopment Area 3—Chromium detected in groundwater, which represents a potential pathway to the river.

10.2.9.3 Loading, Fate, and Transport of Chromium

Chromium loading, fate, and transport assessment for the study area is summarized on Figures 10.2-34a through 10.2-36. Estimated loads from upriver surface water dominate the current loads, exceeding the next highest external loading terms—stormwater and upland groundwater plumes—by more than 2 orders of magnitude. The chromium loads in upstream surface water and at the downstream boundary of the study area are generally comparable, reflecting the absence of significant loads within the study area. The nearshore and off-channel areas of elevated chromium concentrations generally appear to be associated with localized upland sources and pathways.

The cross-media comparison of surface sediments, sediment traps, and suspended solids in surface water (Table 10.2-14a-b and Figure 10.2-34b) show that the study area-wide concentrations of all media are statistically different, with surface sediment having the highest concentrations, followed by sediment traps and then by suspended solids in surface water.

Within the study area, numerous historical and current sources of chromium have been identified for all pathways, but primarily through stormwater discharge. The areas of elevated sediment concentrations generally correspond to the locations of current or former shipyards, wood treatment facilities, pesticide manufacturing, metal recycling operations, steel manufacturing, metal plating operations, and marine repair facilities. Chromium is also identified at some facilities where metal slag and sandblast grit were used as fill. Known and likely current and historical sources of chromium to the study area are summarized in Table 10.2-12 and Panels 10.2-12A–C.

The chromium loading estimates indicate that loads from upriver surface water dominate the current loads, exceeding the next highest external loading terms—stormwater and upland groundwater plumes—by more than 2 orders of magnitude. However, the estimated loads entering and leaving the study area are comparable, suggesting the absence of significant loads within the study area.

10.2.9.4 Human and Ecological Risks Associated with Chromium

Chromium is estimated to posing potentially unacceptable risk to benthic invertebrates, although the risk is of low magnitude and the areal extent is limited.

10.2.10 Tributyltin Ion

A graphical CSM for TBT is presented on Panels 10.2-13A–C. TBT is an organotin compound, and since the mid-1970s has been and is still used as an antifouling agent in paints on the immersed portions of boats and floating structures (Batt

2004). Antifouling paints represent the largest source of TBT in aquatic environments. Many countries restricted the use of antifouling paints based on the risks to shellfish. The U.S. partially banned the use of TBT-based antifouling paints in 1988 (Showalter and Savarese 2005). Use of TBT compounds as slimicides on masonry, disinfectants, and biocides for various industrial processes also may result in their release to the environment.

TBT is an ionic organic compound, and its partitioning behavior is affected by pH and the identity of anions in solution that pair with the TBT ion (Arnold et al. 1997). Specifically, for pH 10 to 7 the measured log K_{oc} values are on the order of 4; from pH 7 to pH 3 they drop to roughly 2. The mean surface water pH in Portland Harbor is 7.4 (10th percentile is 7.0 and 90th percentile is 7.8). Observed pore water pH values range from 5.6 to 8.1. TBT in its nonionic form (not likely observed at the site) is highly hydrophobic, with K_{ow} values on the order of 7 (K_{ow}WIN[12]).

Degradation of organotin compounds involves the breaking of the tin-carbon bond. TBT is subject to different degradation mechanisms depending on its location in the environment. In surface water, it is subject to fairly rapid[13] photodegradation and biodegradation (TBT can be degraded by microbial, microalgal, and fungal populations, as well as by some higher organisms, such as fish; Anderson et al. 2002). Degradation of organotin compounds in sediments is much slower than in water, and half-lives have been estimated to be several years (Alzieu 1998). Abiotic cleavage of the tin-carbon bond by hydrolysis is not an important fate process under environmental conditions (WHO 1990).

While accumulation of TBT from water into organisms may be a significant process that can result in elevated tissue concentrations, subsequent biomagnification through the food web is reportedly minor (ATSDR 2005b).

10.2.10.1 TBT Contaminant Distribution

TBT contamination is sediment is primarily located in the vicinity of the Cascade General Shipyard and adjacent to Swan Island Lagoon. Subsurface sediments exhibit slightly higher concentrations than surface sediments, suggesting that contributions from historical inputs were greater relative to current inputs. Upstream of RM 7.5, TBT was detected in sediment trap samples only in Swan Island Lagoon.

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[12] K_{ow}WIN software available online as part of USEPA Estimation Program Interface (EPI) suite of programs: http://www.epa.gov/oppt/exposure/pubs/episuite.htm

[13] Half-life information for TBT in freshwater could not be found; however, the following information was found for seawater: the half-life of tributyltin in seawater varies, depending on pH, temperature, turbidity, and light; it is generally estimated to be in the range of 1 day to a few weeks (Alzieu 1998). Biodegradation is the major process in seawaters rich in suspended solids, but photolysis, in surface waters, exceeds biodegradation in clean seawater. Calculated half-lives range from 6 days in summertime waters rich in suspended particles to 127 days in clean winter waters (Watanabe et al. 1992).

10.2.10.2 Potential Sources and Pathways of TBT

Within the study area, historical and current sources contributed TBT to the river primarily through the overwater and stormwater pathways. Areas of elevated TBT concentrations correspond with current and former shipyards, where ship hull washing, abrasive blasting, and painting occurred in dry docks and berths (see Map 3.2-10).

Identified known and likely current and historical sources of TBT to the study area are summarized in Table 10.2-13 and Panels 10.2-13A–C. Historical pathways for TBT migration are found at four current and historical shipyard facilities (Cascade General, Gunderson, Mar Com South, and Marine Finance) and include stormwater (four sites) and overwater, overland, and riverbank erosion (two sites). Current known complete or likely complete pathways for TBT have been identified at two sites (Cascade General and Gunderson).

A current and historical known complete stormwater pathway to the river exists at Gunderson, an active manufacturer and refurbisher of railroad cars and marine barges since 1913 (Integral 2007r). Historical likely complete stormwater pathways also exist at Cascade General, Mar Com South, and Marine Finance. Historical overland transport pathways are likely complete at Mar Com South and Marine Finance. Overwater discharge is considered to be the greatest contributor of TBT to the river; current and historical complete pathways for overwater discharge of TBT are found at Cascade General and a complete historical overwater pathway existed at Mar Com South. There are no current or historical groundwater pathways for TBT in the study area. Likely complete historical pathways for riverbank erosion have been identified at Mar Com South and Marine Finance. Information on atmospheric deposition of TBT is very limited, but long-range atmospheric transport of butyltins does occur.

TBT was identified as a COI at two upstream sites, Zidell Marine Corporation site (RM 14W) and Ross Island Sand & Gravel (RM 14.7E), based on detections in sampled media.

10.2.10.3 Loading, Fate, and Transport of TBT

The loading, fate, and transport assessment for TBT in the study area is summarized on Figures 10.2-37a through 10.2-39. Estimated TBT inputs from upriver surface water (11 kg/yr) are lower than those from advection through subsurface sediments (36 kg/yr). The relatively high overall subsurface advective load estimate is driven by localized TBT concentrations at RM 8 to 8.9. Quantitative estimates of internal fate and transport processes were developed only for advection through surface sediments (9.8 kg/yr), which is comparable in magnitude to upstream surface water loading. Advective loading for both pathways is greatest between RM 8 and 8.9 (Figure 10.2-39).

Cross-media comparison and statistical assessment of surface sediments, sediment traps, and suspended solids in surface water (Table 10.2-14a-b and Figure 10.2-37b) show that the concentrations in all media are statistically different.

10.2.10.4 Human and Ecological Risks Associated with TBT

TBT was identified as posing potentially unacceptable risk to fish and benthic invertebrates, though these risks are localized in historical shipyard areas.